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KYNOL/NOMEX FABRICS FOR FIRE RETARDANT SHIPBOARD UTILITY UNIFORMS

NAVY CLOTHING AND TEXTILE RESEARCH FACILITY

NATICK, MASSACHUSETTS

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At the request of the Naval Sea Systems Command, the Navy Clothing & Textile Research Facility (NCTRF) conducted a seven-phase investigation of Kynol/Nomex fabrics for possible use in fire-retardant (FR) shipboard utility uniforms in place of fire-retardant-treated (FRT) cotton. NCTRF first surveyed the U.S. protective clothing market and then tested three Kynol/Nomex blends in its laboratories to determine their physical, abrasion resistance, and laundering properties. Meanwhile, NCTRF ran physiological tests to show the heat stress imposed by the various uniforms and conducted a full array of heat tests ranging from laboratory tests for heat and flame resistance to full-scale flame-envelopment and close-proximity fire tests. NCTRF also administered a shipboard evaluation and subsequently conducted a dyeing and finishing study. Finally, NCTRF completed a cost evaluation of these uniforms. Because these Kynol/Nomex uniforms showed no significant functional heat-resistant benefits over FRT cotton and

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BLOCK 19: ABSTRACT

Cont'd would cost at least twice as much, NCTRF recommended the Navy continue using FRT cotton for the FR shipboard utility uniform. (U)

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EXECUTIVE SUMMARY

The Navy Clothing and Textile Research Facility (NCTRF) was directed by the Naval Sea Systems Command (NAVSEASYSCOM) to assess the potential of Kynol materials for application in utility uniforms. Characteristics such as physical properties, wearability, launderability, heat stress, heat protection, and dyeability were evaluated and compared to the fire retardant treated (FRT) 100% cotton materials previously evaluated and subsequently adopted by the Navy for its fire retardant (FR) shipboard utility uniform.

The investigation included:

a. A general survey of Kynol products marketed in the United States to determine their current use in protective clothing fabrics and availability for application in this program.

b. Laboratory tests to determine the physical, laundering, and abrasion resistance properties of Kynol/Nomex materials with respect to FRT cotton materials.

c. A shipboard evaluation of Kynol/Nomex uniforms with FRT cotton uniforms to establish information regarding fit, comfort, appearance, launderability, durability, and preference.

d. A physiological evaluation to establish the heat stress characteristics of Kynol/Nomex uniforms with respect to the FRT cotton shipboard utility uniform previously evaluated.

e. Heat tests which included laboratory level tests to determine vertical flammability resistance, heat resistance, and protection characteristics for radiant heat and flame impingement exposures; and full scale tests of uniforms to determine protection characteristics in a flame envelopment exposure and in close proximity to a fire.

f. A dyeing and finishing study to establish the potential of coloring Kynol/Nomex fabrics, which are normally only available in their natural gold color, to a suitable blue shade.

g. Potential cost of Kynol/Nomex uniforms versus the FRT cotton uniform.

The general survey of Kynol fabrics established that for protective clothing applications only Kynol fabrics blended with Nomex fibers were available. This resulted in the selection of three Kynol/Nomex fabrics in different weights for evaluation and utilization in two uniform configurations. The lighter weight configuration consisted of a 4.5 oz/yd^2, 70/30% Kynol/Nomex plain weave fabric for the shirt and a 6.0 oz/yd^2, 70/30% Kynol/Nomex plain weave fabric for the trouser. The heavier weight configuration consisted of a 6.0 oz/yd^2, 70/30% Kynol/Nomex plain weave fabric for the shirt (identical to the fabric used in the lighter weight uniform configuration for the trouser), and an 8.0 oz/yd^2, 80/20% Kynol/Nomex twill weave fabric for the trouser.

These fabrics were compared to a 6.5 oz/yd^2, 100% FRT cotton chambray shirt fabric and a 12.0 oz/yd^2, 100% FRT cotton denim trouser fabric recommended for adoption in the Navy's FR shipboard utility uniform. The Navy subsequently selected a 5.5 oz/yd^2, 100% FRT cotton chambray shirt fabric for use with the denim fabric in its FR shipboard utility uniform to improve comfort characteristics but this shirting fabric was not available for inclusion in this study at the time it was initiated.

Results of these evaluations indicated:

a. Survey

Kynol, a novaloid fiber, is manufactured in Japan and is used in the United States on a limited basis. The fiber is relatively weak, and for certain applications such as protective clothing fabrics, is blended with Nomex aramid fibers to improve the strength and abrasion resistance of the resulting fabrics. The Kynol fiber is difficult to dye and is normally marketed today in its natural gold color.

b. Laboratory Tests

1. The Kynol/Nomex and FRT cotton fabrics had suitable strength characteristics for utilization in a utility uniform.

2. The undyed Kynol/Nomex fabrics had poor abrasion resistance compared to the FRT cotton fabrics. The cotton materials were superior to the Kynol/Nomex fabrics by a factor of at least 1.7 to 1 for the shirting fabrics and at least 2.9 to 1 for the trouser fabrics, indicating the cotton uniform would have a longer potential use life than the Kynol/Nomex uniforms. This held true for the most part when the FRT cotton fabrics were compared to dyed Kynol/Nomex fabrics, except in one instance where one of the dyed Kynol/Nomex shirting fabrics was slightly better than the FRT cotton shirting fabric in abrasion resistance.

3. Both the Kynol/Nomex and FRT cotton fabrics showed progressive shrinkage with multiple launderings indicating similar potential fit problems after laundering with both types of fabrics, although in the ship tests the cotton uniform performed slightly better than the Kynol/Nomex uniforms in this respect.

4. Multiple launderings caused loss of hand (limpness) with the Kynol/Nomex fabrics. The hand of the FRT cotton fabrics was also affected but not to the extent observed with the Kynol/Nomex materials.

c. Shipboard Evaluation

1. The FRT cotton uniform (6.5 oz/yd^2 chambray shirt and 12.0 oz/yd^2 denim trouser) was favored by user personnel by 3.2 to 1 over the heavyweight (HW) Kynol/Nomex uniform (6.0 oz/yd^2, 70/30% Kynol/Nomex shirt and 8.0 oz/yd^2, 80/20% Kynol/Nomex trouser).

2. The HW Kynol/Nomex uniform was preferred 1.3 to 1 over the lightweight (LW) Kynol/Nomex uniform (4.5 oz/yd^2, 70/30% Kynol/Nomex shirt and 6.0 oz/yd^2, 70/30% Kynol/Nomex trouser). Eighteen percent of those who wore both of these uniforms did not prefer either one.

3. Regarding the individual performance characteristics assessed (fit, comfort, appearance, launderability, and durability) both the Kynol/Nomex and FRT cotton uniforms were rated equivalently for most factors. When there were differences, though not substantial, the cotton uniform was favored over the Kynol/Nomex uniforms for fit after laundering and for trouser comfort. The LW Kynol/Nomex shirt was favored over both the HW Kynol/Nomex and cotton shirts for comfort.

d. Physiological Evaluation

In this evaluation no significant differences in heat stress indicators (tolerance time, rectal temperature rise, skin temperature rise) were found between the FRT cotton and Kynol/Nomex uniforms. Based on subjective comments, the cotton uniform was rated the most comfortable followed by the LW Kynol/Nomex uniform. The HW Kynol/Nomex uniform was disliked by all test volunteers.

e. Heat Tests

1. Vertical flammability resistance was excellent and similar for both the Kynol/Nomex and FRT cotton fabrics, new and after fifteen simulated shipboard launderings.

2. The Kynol/Nomex fabrics were superior to the FRT cotton fabrics in radiant heat resistance measured as char through time. The higher Nomex blended Kynol/Nomex fabrics showed better radiant heat resistance than the lower Nomex blended Kynol/Nomex fabrics. However, in subsequent radiant heat tests to establish burn time protection provided by the fabrics it was determined that burn injury would have been sustained with the Kynol/Nomex fabrics long before char through would have occurred with the cotton fabrics at equivalent heat flux levels, negating to some degree, the value of the higher heat resistance provided by the Kynol/Nomex fabrics.

3. Heat protection in radiant heat and flame impingement tests measured as time to burn injury was related to fabric weight and not to fiber type. The heavier the fabric the greater the protection time. The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the FRT cotton materials.

4. Flame envelopment tests showed the HW Kynol/Nomex uniform and FRT cotton uniform gave equivalent protection measured as percent body area burned. The protection provided by the LW Kynol/Nomex uniform was significantly less than attained with the HW Kynol/Nomex and cotton uniforms in these tests. In the close proximity fire tests, the cotton uniform provided better protection than either the LW or HW Kynol/Nomex uniforms. As in the lab scale tests, protection was more related to the weight of the uniforms than to the fibers from which they were made.

f. Dyeing and Finishing Study

There was some degree of success in dyeing the Kynol/Nomex fabrics to a suitable Navy blue shade. Colorfastness was judged to be acceptable except for lightfastness and staining of the nylon component of the multifiber control swatch. Colorfastness to light will always be poor regardless of the quality of the dyeings for the Kynol fibers because they darken when exposed to ultraviolet radiation causing the material to appear darker. A finish was applied to the Kynol/Nomex fabrics which increased their abrasion resistance over the undyed and desized fabrics by a factor of 3. Even with this improvement in abrasion resistance, except for one case where one of the dyed Kynol/Nomex shirting fabrics was slightly better than the FRT cotton shirting fabric in this property, as mentioned earlier, the FRT cotton fabrics for the most part were still superior in abrasion resistance to their Kynol/Nomex fabric shirting and trouser counterparts. The remaining dyed fabric properties remained basically the same as the undyed fabrics with the exception of breaking strength which on the average improved because of the application of the finish, and tear strength which was lower after production dyeing for two of the test fabrics when compared to the undyed fabric values. The dyeing and finishing of the fabrics would increase their cost by at least 20%.

g. Potential Cost of Kynol Uniforms

The cost of the HW Kynol/Nomex uniform was estimated to be at least 2.8 times higher than the FRT cotton uniform whereas the LW Kynol/Nomex uniform would be at least 2.3 times more costly than the cotton uniform.

Recommendations

a. Considering the Kynol/Nomex uniforms showed no significant functional or heat protection advantages over the FRT cotton uniform and would be at least 2.3 times more expensive than the cotton uniform, the cotton uniform should continue to be used by the Navy for its FR Shipboard Utility Uniform.

b. The Kynol/Nomex fabrics would be better utilized in applications where heat resistance rather than heat protection is the prime need.

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KYNOL/NOMEX FABRICS FOR FIRE-RETARDANT SHIPBOARD UTILITY UNIFORMS

INTRODUCTION

The Navy Clothing and Textile Research Facility (NCTRF) was directed by the Naval Sea Systems Command (NAVSEASYSCOM) to assess the potential of Kynol materials for application in utility uniforms. Characteristics such as physical properties, wearability, launderability, heat stress, heat protection, and dyeability were evaluated and compared to the fire retardant treated (FRT) 100% cotton materials previously evaluated and subsequently adopted by the Navy for its fire retardant (FR) shipboard utility uniform.

The investigation included:

a. A general survey of Kynol products marketed in the United States to determine their current use in protective clothing fabrics and availability for application in this program.

b. Laboratory tests to determine the physical, laundering, and abrasion resistance properties of Kynol/Nomex materials with respect to FRT cotton materials.

c. A shipboard evaluation of Kynol/Nomex uniforms with FRT cotton uniforms to establish information regarding fit, comfort, appearance, launderability, durability, and preference.

d. A physiological evaluation to establish the heat stress characteristics of Kynol/Nomex uniforms with respect to the FRT cotton shipboard utility uniform previously evaluated.

e. Heat tests which included laboratory level tests to determine vertical flammability resistance, heat resistance, and protection characteristics for radiant heat and flame impingement exposures; and full scale tests of uniforms to determine protection characteristics in a flame envelopment exposure and in close proximity to a fire.

f. A dyeing and finishing study to establish the potential of coloring Kynol/Nomex fabrics, which are normally only available in their natural gold color, to a suitable blue shade.

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The general survey of Kynol fabrics established that for protective clothing applications only Kynol fabrics blended with Nomex fibers were available. This resulted in the selection of three Kynol/Nomex fabrics in different weights for evaluation and utilization in two uniform configurations. The lighter weight configuration consisted of a 4.5 oz/yd^2, 70/30% Kynol/Nomex plain weave fabric for the shirt and a 6.0 oz/yd^2, 70/30% Kynol/Nomex plain weave fabric for the trouser. The heavier weight configuration consisted of a 6.0 oz/yd^2, 70/30% Kynol/Nomex plain weave fabric for the shirt (identical to the fabric used in the lighter weight uniform configuration for the trouser), and an 8.0 oz/yd^2, 80/20% Kynol/Nomex twill weave fabric for the trouser. These fabrics were compared to a 6.5 oz/yd^2, 100% FRT cotton chambray shirt fabric and a 12.0 oz/yd^2, 100% FRT cotton denim trouser fabric recommended for adoption in the Navy's FR shipboard utility uniform. The Navy subsequently selected a 5.5 oz/yd^2, 100% FRT cotton chambray shirt fabric for use with the denim fabric in its FR shipboard utility uniform to improve comfort characteristics but this shirting fabric was not available for inclusion in this study at the time it was initiated. The fire retardant treatment used for the cotton fabrics was tetrakis (hydroxymethyl) phosphonium hydroxide cured in a gaseous ammonia atmosphere ($THPOH-NH_3$) a well known durable fire retardant treatment for cotton.

Results of these evaluations indicated:

a. Survey

Kynol, a novaloid fiber, is manufactured in Japan and is used in the United States on a limited basis. The fiber is relatively weak, and for certain applications such as uniform fabrics, is blended with Nomex aramid fibers to improve the strength and abrasion resistance of the resulting fabrics. The Kynol fiber is difficult to dye and is normally marketed today in its natural gold color. The available Kynol/Nomex fabrics selected for this study and felt most suitable for application in a utility uniform were a 4.5 oz/yd^2, 70/30% Kynol/Nomex blend, and a 6.0 oz/yd^2, 70/30% Kynol/Nomex blend for a lightweight (LW) shirt/trouser uniform and a 6.0 oz/yd^2, 70/30% Kynol/Nomex blend and an 8.0 oz/yd^2, 80/20% Kynol/Nomex blend for a heavyweight (HW) shirt/trouser uniform.

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1. The Kynol/Nomex and FRT cotton fabrics had suitable strength characteristics for utilization in a utility uniform.

2. The undyed Kynol/Nomex fabrics had poor abrasion resistance compared to the FRT cotton fabrics. The cotton materials were superior to the Kynol/Nomex fabrics by a factor of at least 1.7 to 1 for the shirting fabrics and at least 2.9 to 1 for the trouser fabrics, indicating potentially better long term wear characteristics for the cotton materials with respect to the Kynol/Nomex materials. This held true for the most part when the FRT cotton fabrics were compared to the dyed Kynol/Nomex fabrics, except in one instance when one of the dyed Kynol/Nomex shirting fabrics was slightly better than the FRT cotton shirting fabric in abrasion resistance.

3. Both the Kynol/Nomex and FRT cotton fabrics showed progressive shrinkage with multiple launderings indicating similar potential fit problems after laundering with both types of fabrics, although in the ship tests the cotton uniform performed slightly better than the Kynol/Nomex uniforms in this respect.

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3. Heat protection in radiant heat and flame impingement tests measured as time to burn injury was related to fabric weight and not to fiber type. The heavier the fabric the greater the protection time. The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the FRT cotton materials.

4. The time to burn injury measured in the radiant heat tests occurred with all of the Kynol/Nomex fabrics long before char through would have occurred for the cotton fabrics at equivalent heat flux levels. The benefit of using the higher heat resistant Kynol/Nomex fabrics is somewhat negated since burn injury is sustained long before char through occurs.

5. Flame envelopment tests showed the HW Kynol/Nomex uniform and FRT cotton uniform gave equivalent protection measured as percent body area burned. The protection provided by the LW Kynol/Nomex uniforms was significantly less than attained with the HW Kynol/Nomex and cotton uniforms in these tests. In the close proximity fire tests the cotton uniform provided better protection than either the LW or HW Kynol/Nomex uniform. As in the lab scale tests, protection was more related to the weight of the uniforms than to the fibers from which they were made.

f. Dyeing and Finishing Study

There was some degree of success in dyeing the Kynol/Nomex fabrics to a suitable Navy blue shade. Colorfastness was judged to be acceptable for laundering, crocking, and perspiration, but was poor for lightfastness and staining of the nylon component of the multifiber control swatch. The Kynol materials darkened under accelerated exposure to light, a characteristic inherent to phenolic fibers. A finish was applied to the Kynol/Nomex fabrics which increased their abrasion resistance over the undyed desized fabrics by a factor of 3. Even with this improvement in abrasion resistance, except for one case where one of the dyed Kynol/Nomex shirting fabrics was slightly better than the FRT cotton shirting fabric in this property, as mentioned earlier, the FRT cotton fabrics for the most part were still superior in abrasion resistance to their Kynol/Nomex fabric shirting and trouser counterparts. The remaining dyed fabric properties remained basically the same as the undyed fabrics with the exception of breaking strength which on the average improved because of the application of the finish, and tear strength which was lower after production dyeing for two of the test fabrics when compared to the undyed fabric values. The dyeing and finishing of the fabrics would increase their cost by at least 20%.

g. Potential Cost of Kynol Uniforms

The cost of the HW Kynol/Nomex uniform was estimated to be at least 2.8 times higher than the FRT cotton uniform whereas the LW Kynol/Nomex would be at least 2.3 times more costly than the cotton uniform. Considering there would be no particular benefit derived from using the Kynol/Nomex uniforms either from a functional or heat protection consideration compared to the cotton uniform, it would be prudent to continue to use the cotton fabrics for the Navy's shipboard FR utility uniform.

This report includes laboratory, shipboard, physiological, heat protection and the dyeing and finishing study results, and cost factors associated with producing Kynol/Nomex fabrics and uniforms. Herein the FRT cotton fabrics will be identified only as cotton fabrics.

KYNOL PRODUCTS REVIEW

A survey was conducted of commercial protective materials and their clothing applications to determine sources of Kynol fabrics suitable for use in utility uniforms and to obtain some background on the current applications of these materials. Results of the survey indicated that current use of these fabrics is limited and when used are employed in their undyed natural gold color.

Kynol, a novaloid fiber, invented by the Carborundum Company in 1968, is a high performance phenolic fiber with inherent flame and chemical resistance properties. Commercial development and production of Kynol has been carried out in Japan since 1972 by the Gynei Chemical Industry Co., who market fabrics in Japan through Nippon Kynol Inc. The exclusive United States distributor of Kynol yarns and fabrics is American Kynol, Inc. (AKI).

Utilizing AKI as an information base, a listing of commercial companies, past and present, having any experience with Kynol materials, was compiled. All the companies were contacted by telephone and follow-up letter. Information was requested concerning the specific product type available, intended application, and any experiences regarding performance of Kynol fabrics. Of thirty two companies contacted, only five still included Kynol in their product line. Several companies, seeking alternative fabrics for their protective products, experimented with Kynol and Kynol blended fabrics, but found them unsuitable. Some of the negative comments received on the Kynol fabrics were: poor strength, poor abrasion resistance, expensive as compared to other FR fabrics, and extremely limited color range with poor colorfastness properties.

Suppliers of protective clothing indicated minimal use of Kynol fabrics for gloves, shirts, trousers, coveralls, and some specialty items. In all cases, the materials used were not 100% Kynol, but a blend with other fibers. Chemfab, a material producer located in Bennington, Vermont, was found to be the only manufacturer weaving Kynol materials in the United States. All other Kynol materials were found to be imported from Japan.

Survey information also revealed that Kynol materials were available in woven, knit and batting structures, incorporating either spun or filament yarns. Since Kynol is a relatively weak fiber, the fiber is blended with glass or aramid (Nomex) fabrics for certain applications to improve strength and abrasion resistance. Kynol yarns are usually spun on a modified woolen system producing yarns as fine as 20 TEX when blended with 30% Nomex fiber, and as coarse as 300 TEX for 100% Kynol yarns. Fabric weights ranged from 3.0 to 16.0 oz/yd^2.

Gold is the natural color of Kynol fiber. Most all material samples and garments obtained for analysis were in the gold color. Although promotional literature published by AKI indicated that Kynol can be dyed using dispersed and cationic dyes, colors are limited by the fiber's natural gold color. Dark shades can be obtained, but light shades cannot. Commercial practice indicated that most Kynol fabrics are utilized undyed and in some cases with a permanent press finish. In one case, the fabric was blended with cotton fiber to permit dyeing the fabric a yellow color. During a meeting held between Dr. Fugi, President of Nippon Kynol, Inc., Mr. J. Hayes, American Kynol, Inc., and NCTRF personnel, dyed Kynol fabrics were discussed. Although no commercial dyeing of Kynol fabrics is currently being done in the United States or Japan, two material samples in a blue and black shade were obtained from Dr. Fugi. The samples were dyed in Japan in 1974.

As a result of the survey, three fabrics were selected for evaluation in this program. The fabrics chosen were: (1) 4.5 oz/yd^2, 70/30% Kynol/Nomex, plain weave; (2) 6.0 oz/yd^2, 70/30% Kynol/Nomex, plain weave, and (3) 8.0 oz/yd^2, 80/20% Kynol/Nomex, twill weave. The fabrics were utilized in both LW and HW uniform combinations. The LW uniform was comprised of the 4.5 oz/yd^2 fabric for the shirt and 6.0 oz/yd^2 fabric for the trouser. The HW uniform contained the 6.0 oz/yd^2 fabric for the shirt and the 8.0 oz/yd^2 fabric for the trouser.

It was quite evident from the survey conducted that Kynol materials in any other color than gold, the fiber's natural color, were not available. It was further determined that information on procedures for dyeing the fabrics to a specified color with acceptable colorfastness properties was not available.

To resolve the dyeing problem, particularly that associated with dyeing the fabrics to an acceptable Navy blue shade, a dyeing feasibility study was conducted under contract for the Navy by Albany International Research Co. Results of this study are contained in Tab E of this report.

MATERIALS INVESTIGATION

INTRODUCTION

The three Kynol/Nomex materials and two 100% cotton materials used in this program were evaluated to determine their relative physical, laundering, and abrasion resistance properties. Table I shows the materials tested, their salient characteristics and the type of garment in which they were utilized.

TABLE I MATERIALS EVALUATED

Material	Weight (oz/yd^2)	Weave	Shade	Utilization
70/30% Kynol/Nomex	4.5	Plain	Gold	Shirt
70/30% Kynol/Nomex	6.0	Plain	Gold	Shirt Trouser
80/20% Kynol/Nomex	8.0	Twill	Gold	Trouser
100% FRT Cotton	6.5	Chambray	Light Blue	Shirt
100% FRT Cotton	12.0	Denim	Dark Blue	Trouser

The material evaluations included the analysis of fabric properties related to construction, breaking strength, tear strength, air permeability, abrasion resistance, and dimensional stability. Additionally, fifteen simulated shipboard launderings using Navy Wash Formula II were performed on garments manufactured from these materials to determine garment shrinkage characteristics and changes in appearance and hand as a result of laundering.

PROCEDURES

The test procedures employed were applicable test methods described in Federal Standard for Textile Test Methods No. 191 (Table II). Procedures for the simulated shipboard launderings of garments made from these materials are detailed in Tab A.

RESULTS

Material Properties

The properties for the shirting materials are shown in Table III and in Table IV for the trouser materials.

Shirt Materials (Table III)

The lighter Kynol/Nomex (4.5 oz/yd^2) and cotton (6.5 oz/yd^2) fabrics had similar break and tear strength properties while the heavier Kynol/Nomex (6.0 oz/yd^2) fabric had superior warp break and tear strength. The lighter Kynol/Nomex fabric had superior air permeability properties compared to the cotton and heavier Kynol/Nomex fabrics. The dimensional stability of the cotton fabrics was better than either of the Kynol/Nomex fabrics although the values obtained for the Kynol/Nomex fabrics were considered suitable.

The abrasion resistance for the cotton fabric was superior to both Kynol/Nomex fabrics, particularly with respect to the lighter Kynol/Nomex fabric.

Trouser Materials (Table IV)

The break and tear strengths were similar for all the trouser materials. The air permeabilities were also similar and low (21 $ft^3/min/ft^2$ or less). The cotton material showed better dimensional stability but the values for the Kynol/Nomex materials were considered suitable. The major difference in these materials was related to abrasion resistance. The cotton fabric had an abrasion resistance at least 2.9 times greater than the Kynol/Nomex materials.

TABLE II TEST METHODS FOR DETERMINING PROPERTIES OF MATERIALS

Property	Title	Federal Standard No 191A
Weave	Visual	----
Weight	Weight of Textile Materials; Small Specimen Method	5041
Ends/Picks Per Inch	Yarns per Unit Length in Woven Cloth	5050
Break Strength	Strength and Elongation, Breaking of Woven Cloth - Grab Method	5100
Tear Strength	Strength of Cloth, Tearing Falling Pendulum Method	5132
Air Permeability	Permeability to Air, Cloth; Calibrated Orifice Method	5450
Flammability	Flame Resistance of Cloth; Vertical	5903
Laundering Shrinkage	Mobile Laundry Evaluation for Textile Materials	5556
Abrasion	Abrasion Resistance of Cloth; Inflated Diaphram Method	5302

TABLE III SHIRT FABRIC PROPERTIES

Physical Characteristics	Material		
	Kynol/Nomex	Kynol/Nomex	FRT Cotton
Blend (%)	70/30	70/30	100
Weave	Plain	Plain	Plain
Weight (oz/yd^2)	4.5	6.0	6.5
Ends/Inch	54	82	76
Picks/Inch	46	45	57
Break Strength (lbs)			
Warp	104	178	110
Filling	76	85	90
Tear Strength (lbs)			
Warp	6	10	5
Filling	5	5	4
Air Permeability ($ft^3/min/ft^2$)	132	21	49
Yarn Ply	2	2	1
Dimensional Stability (%)			
Warp	2.1	1.9	1.0
Filling	2.0	1.9	0.5
Abrasion (Cycles)	280	710	1190

TABLE IV TROUSER FABRIC PROPERTIES

Physical Characteristics	Material Kynol/Nomex	Material Kynol/Nomex	Material FRT Cotton
Blend (%)	70/30	80/20	100
Weave	Plain	2/1 Twill	2/1 Twill
Weight (oz/yd^2)	6.0	8.0	12.0
Ends/Inch	82	74	70
Picks/Inch	45	51	43
Break Strength (lbs)			
Warp	178	174	180
Filling	85	100	104
Tear Strength (lbs)			
Warp	10	10	8
Filling	5	6	5
Air Permeability (ft^3/min/ft^2)	21	20	12
Yarn Ply	2	2	1
Dimensional Stability (%)			
Warp	1.9	1.9	1.2
Filling	1.9	2.0	1.0
Abrasion (Cycles)	710	1700	5000

Shipboard Launderings of Garments

The results of these tests are shown in Table V. All of the shirting and trouser garments constructed from the cotton and Kynol/Nomex fabrics showed progressive shrinkage. For the shirts, the cotton shirt performed best (4.2% maximum shrinkage after 15 launderings) while the Kynol/Nomex shirts had shrinkage values of 7.0% or more after 15 launderings. For the trousers, the lighter weight Kynol/Nomex garment was best (4.4% maximum shrinkage value after 15 launderings). The cotton and heavier Kynol/Nomex trousers had maximum shrinkage values of 6.1% and 6.9%, respectively, after 15 launderings. Based on these results, fitting problems after multiple launderings can be anticipated for all the cotton and Kynol/Nomex shirt and trouser garments.

TABLE V GARMENT SHRINKAGE AFTER FIFTEEN SHIPBOARD LAUNDERINGS IN THE LENGTH AND WIDTH DIRECTIONS

Item	Type	Weight (oz/yd^2)	Direction	Shrinkage (%) No. of Washings 1	3	5	10	15
Shirt	Cotton	6.5	W	0.1	1.1	1.7	2.6	4.2
			F	0.8	1.0	0.9	1.6	2.8
	Kynol/Nomex	4.5	W	2.5	5.0	5.7	6.4	7.8
			F	0.2	0.2	0.2	0.6	1.5
	Kynol/Nomex	6.0	W	3.1	4.5	5.3	5.7	7.0
			F	0.3	0.4	0.7	0.9	1.8
Trouser	Cotton	12.0	WA	1.4	3.5	1.7	4.9	3.9
			IL	1.2	3.1	2.6	4.0	6.1
	Kynol/Nomex	6.0	WA	2.6	1.4	1.9	3.5	3.8
			IL	1.2	1.7	1.5	3.5	4.4
	Kynol/Nomex	8.0	WA	3.1	4.0	4.2	5.9	5.1
			IL	2.2	3.2	2.9	4.2	6.9

W = Warp
F = Filling
WA = Waist
IL = Inseam Length

After the third laundering cycle it was noted that all the garments had poor appearance (wrinkles). After 15 launderings all of the garments had lost their initial hand. This was more severe with the Kynol/Nomex garments where the fabrics felt very limp. There was also some pilling noted on the Kynol/Nomex garments, particularly the items manufactured from the 4.5 and 6.0 oz/yd^2 fabrics.

CONCLUSIONS

The major differences noted between the materials and garments were:

1. The lighter weight Kynol/Nomex shirt fabric had significantly better air permeability characteristics than the cotton and heavier Kynol/Nomex shirt fabrics. All trouser fabrics had similar low air permeability values.

2. The abrasion resistance of the cotton shirt and trouser fabrics was significantly superior to their Kynol/Nomex counterparts.

3. The hand of the Kynol/Nomex fabrics was more negatively affected by laundering than the cotton fabrics (very limp)

For further information see Tab A.

SHIPBOARD EVALUATION

INTRODUCTION

The shipboard evaluation was designed and conducted to determine the acceptability of Kynol/Nomex materials incorporated in the design of the standard Man's Enlisted Utility Uniform.. The Kynol/Nomex uniforms, comprised of shirts and trousers, were constructed in two styles; a LW and a HW version. The uniforms were tested under shipboard conditions, along with a cotton uniform previously recommended for the Navy's FR shipboard utility uniform for comparative purposes.

The LW and HW Kynol/Nomex uniforms and the cotton uniform are shown in Figs. 1, 2, and 3. Uniform comparison data were acquired through personnel questionnaire input.

MATERIALS

Table VI illustrates the fabric make up of each of the uniforms and their codes. Table VII shows how the uniforms were compared and the number of personnel involved in the shipboard evaluation.

TABLE VI SHIRT/TROUSER MATERIALS AND CODES
EMPLOYED IN THE SHIPBOARD EVALUATION

Material	Weave	Weight (oz/yd^2)	Code	Item
100% FRT Cotton Chambray	Plain	6.5	A	Shirt
100% FRT Cotton Denim	Plain	12.0	B	Trouser
70% Kynol/30% Nomex	Plain	6.0	C	Shirt
80% Kynol/20% Nomex	Twill	8.0	D	Trouser
70% Kynol/30% Nomex	Plain	4.5	E	Shirt
70% Kynol/30% Nomex	Plain	6.0	F	Trouser

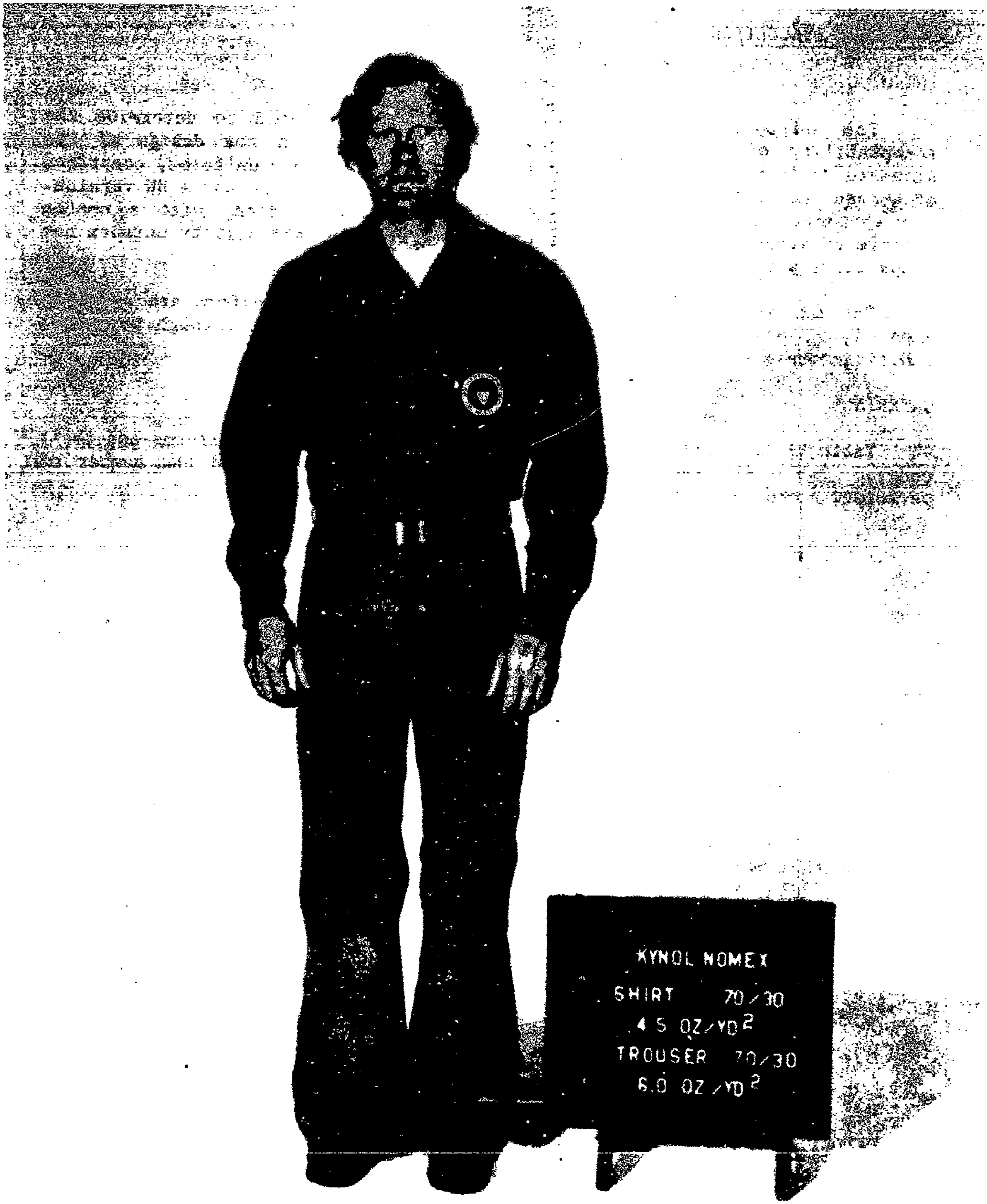


Fig. 1

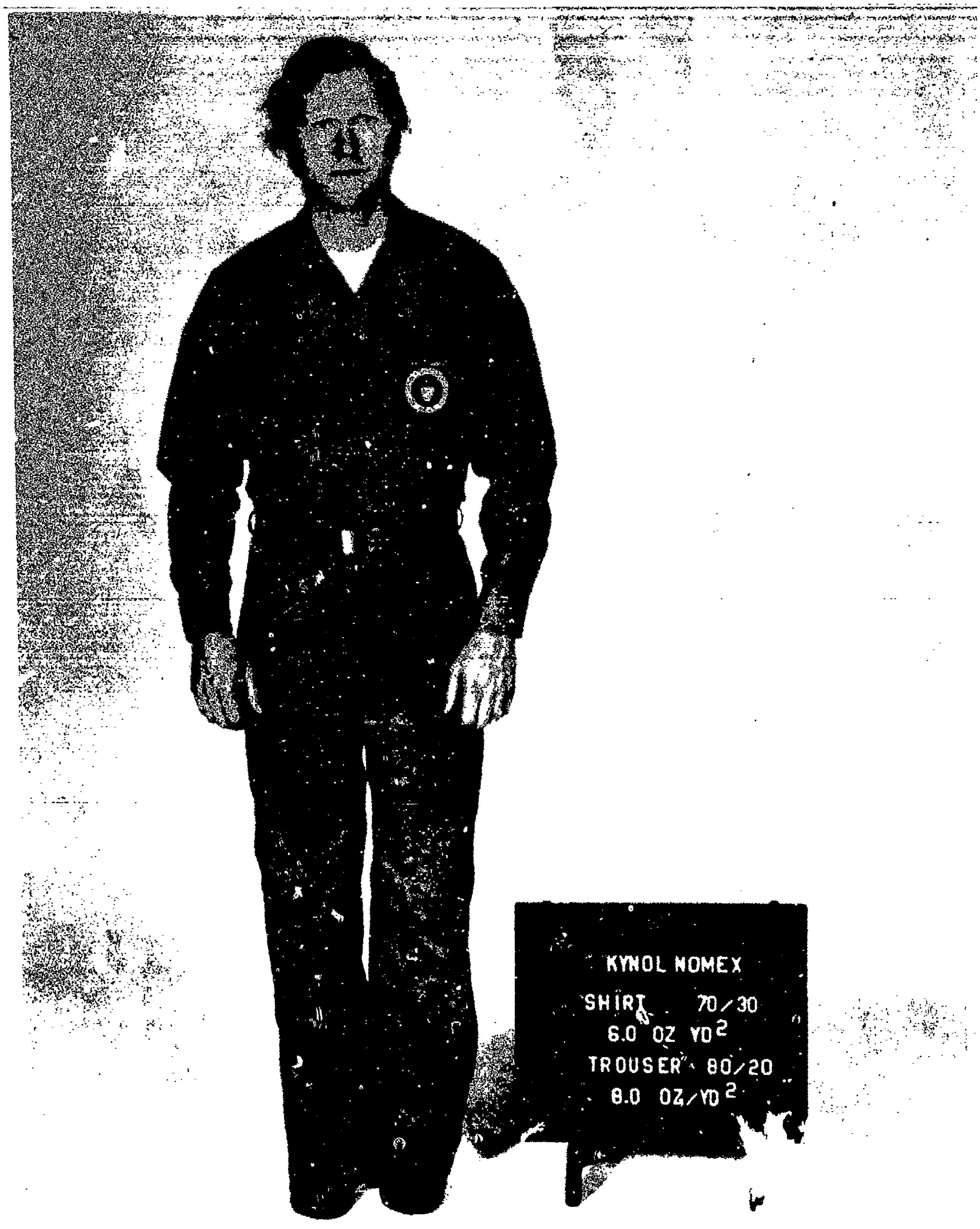


Fig. 2

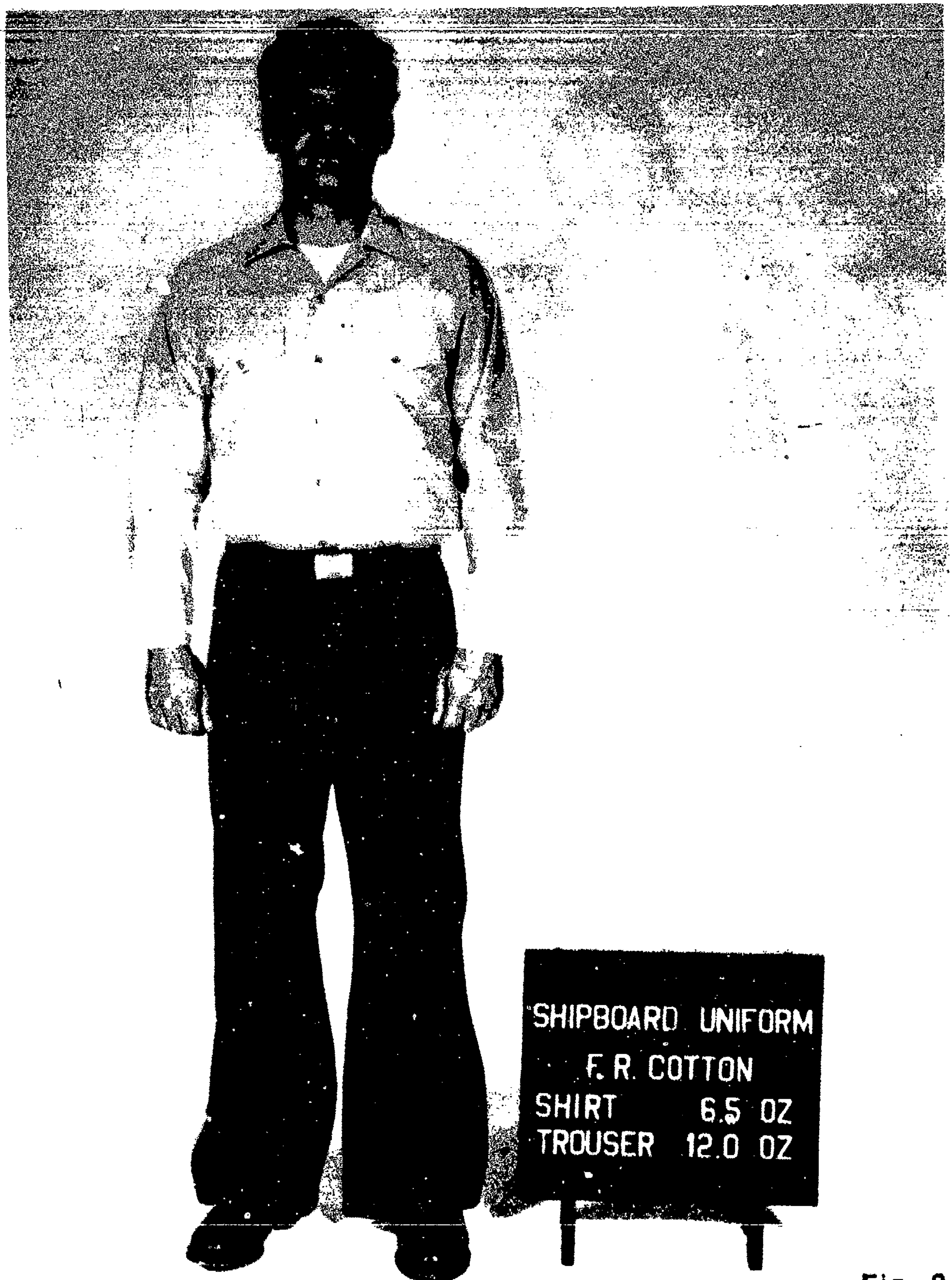


Fig. 3

TABLE VII UNIFORM COMPARISONS

Uniform	Code	vs	Uniform	Code	No. Personnel
Cotton	AB		HW Kynol/Nomex	CD	182
LW Kynol/Nomex	EF		HW Kynol/Nomex	CD	180

SHIP EVALUATION

The ship evaluation was conducted from September 1984 to November 1984 aboard four surface ships. On two ships, the USS CLAUDE V. RICKETTS and the USS SIDES, 180 personnel evaluated the LW Kynol/Nomex versus HW Kynol/Nomex uniforms. On the USS CONCORD and USS ARCADIA, 182 personnel evaluated the cotton uniform versus the HW Kynol/Nomex uniform.

RESULTS

The questionnaire information obtained provided data on appearance, fit, comfort, durability, heat protection and preference of uniform. In the initial outfitting of the uniforms, NCTRF measured various personnel and provided uniforms to those who best fit the uniform size range available. Available test ships were also re-visited at the end of the wear test to confirm questionnaire data received on a monthly basis. All significant data received were confirmed to be valid.

HW Kynol/Nomex Versus Cotton Uniform

A summary of the questionnaire data is contained in Table VIII. The average daily wear of each uniform was recorded to be between 5 to 8 times per month, with each uniform being washed 3 to 5 times per month.

The cotton and Kynol/Nomex uniforms were rated equivalent in appearance after laundering. Fit after laundering was rated better for the cotton uniform than the Kynol/Nomex uniform (shirt 81% vs. 73%, trouser 68% vs. 55%).

At an average temperature range between 71^{o}F and 90^{o}F most found both uniforms uncomfortable. Only 18 to 19% indicated both shirts were comfortable, while 42% found the cotton trouser comfortable and only 33% found the Kynol/Nomex trouser comfortable.

Durability of both uniforms was equivalent. Little to some wear was noted by at least 85% of the test participants for both uniforms.

Heat protection for those personnel who indicated exposure to flames, sparks and high temperatures was equivalent. Sixty five to sixty seven percent indicated both uniforms provided good to excellent protection.

The questionnaire preference data clearly indicated that personnel preferred the cotton uniform over the Kynol/Nomex uniform (76% vs 24%). Although there were few noted functional differences between the two uniforms the preference for the cotton uniform to the Kynol/Nomex uniform was very significant.

TABLE VIII COMPARISON OF FRT COTTON UNIFORM AND HEAVYWEIGHT KYNOL/NOMEX UNIFORM

Factor	Response	FRT Cotton Shirt	FRT Cotton Trouser	Kynol/Nomex Shirt	Kynol/Nomex Trouser
Times Garment Worn per Month	Number	5-8	5-8	5-8	5-8
Times Garment Laundered per Month	Number	3-5	3-5	3-5	3-5
Appearance After Laundering (%)	Good to Excellent	67	69	66	66
Fit After Laundering (%)	Yes	81	68	73	55
Comfort (%)	Good	19	42	18	33
Durability (%) (Wear)	Little to Some	88	85	87	86
Heat Protection	Good to Excellent	65		67	
Preference (%)		76		24	

HW Kynol/Nomex Uniform versus LW Kynol/Nomex Uniform

A summary of the questionnaire data is contained in Table IX. The average daily wear of the uniforms was between 5 and 8 times per month, with each uniform being washed 3 to 5 times per month.

After laundering, both shirts were judged to have good to excellent appearance by 60 to 62% of the test participants and both trousers were judged the same by 56 to 59%. Fit after laundering was equivalent for both uniforms. The fit of the shirts was rated better than the trousers (75 to 78% vs. 66%).

At an average temperature range of 71°F to 90°F, the LW Kynol/Nomex uniform was rated slightly better for comfort than the HW Kynol/Nomex uniform. (shirt 54 to 46%, trouser 55 to 49%).

In terms of durability, both uniforms were equivalent. Both were indicated to have little or some wear by at least 86% of the participants.

Heat protection for those individuals who indicated exposure to flames, sparks, and high temperatures was similar. Fifty six to fifty eight percent indicated good to excellent protection.

The questionnaire preference data indicated that personnel preferred the HW Kynol/Nomex uniform over the LW Kynol/Nomex uniform by 46% to 36%. Eighteen percent preferred neither uniform.

There were few noted functional differences between these uniforms and the preference difference for each was not substantial.

TABLE IX COMPARISON OF HEAVYWEIGHT KYNOL/NOMEX UNIFORM AND LIGHTWEIGHT KYNOL/NOMEX UNIFORM

Factor	Response	HW Uniform Shirt	HW Uniform Trouser	LW Uniform Shirt	LW Uniform Trouser
Times Garment Worn per Month	Number	5-8	5-8	5-8	5-8
Times Garment Laundered per Month	Number	3-5	3-5	3-5	3-5
Appearance After Laundering (%)	Good to Excellent	60	59	62	56
Fit After Laundering (%)	Yes	75	66	78	66
Comfort (%)	Good	46	49	54	55
Durability (%) (Wear)	Little to Some	87	88	87	86
Heat Protection	Good to Excellent	58		56	
Preference (%)	HW	46			
	LW	36			
	None	18			

DISCUSSION

Table X illustrates the relative performance ratings for each uniform comparison. In the cotton uniform versus HW Kynol/Nomex uniform comparison, the cotton uniform was preferred by 3.2 to 1 over the HW Kynol/Nomex uniform. After laundering, the fit of the cotton uniform was rated slightly better than the HW Kynol/Nomex uniform (shirt 1.1 to 1, trouser 1.2 to 1). The trouser of the cotton uniform was rated more comfortable than the Kynol/Nomex trouser by 1.3 to 1. The shirts were equivalent in comfort. Appearance after laundering, durability, and heat protection were rated equivalently for each uniform.

In the HW Kynol/Nomex uniform versus the LW Kynol/Nomex uniform comparison, the HW uniform was preferred by 1.3 to 1 over the LW uniform. The only functional difference noted in these uniforms related to comfort. The shirt and trouser for the LW uniform were rated slightly better for comfort than the HW uniform (shirt 1.2 to 1, trouser 1.1 to 1).

Relative data between the two uniform comparisons (cotton vs. HW Kynol/Nomex and HW Kynol/Nomex vs LW Kynol/Nomex) suggests the cotton uniform would be highly preferred over either Kynol/Nomex uniform and fit after laundering would be slightly better with the cotton uniform than either Kynol/Nomex uniform. All other properties except comfort (appearance after laundering, durability, and heat protection) would be similar for the cotton and Kynol/Nomex uniform types. For comfort, the cotton trouser would provide slightly better comfort than the trousers for the two Kynol/Nomex uniforms, while the LW Kynol/Nomex shirt would provide slightly better comfort than the cotton shirt and HW Kynol/Nomex shirt.

CONCLUSIONS

The performance information obtained on the cotton and Kynol/Nomex uniforms showed no substantial functional differences between these uniforms. However, the degree to which the cotton uniform was preferred by the test participants to the Kynol/Nomex uniforms was very significant.

For further information see Tab B.

TABLE X RELATIVE PERFORMANCE RATINGS FOR THE FRT COTTON VS HEAVYWEIGHT KYNOL/NOMEX UNIFORM AND HEAVYWEIGHT KYNOL/NOMEX VS LIGHTWEIGHT KYNOL/NOMEX UNIFORM

Factor	Component	FRT Cotton	Vs.	HW Kynol/ Nomex	HW Kynol/ Nomex	Vs.	LW Kynol/ Nomex
Appearance After	Shirt	1	to	1	1	to	1
Laundering	Trouser	1	to	1	1	to	1
Fit After	Shirt	1.1	to	1	1	to	1
Laundering	Trouser	1.2	to	1	1	to	1
Comfort	Shirt	1	to	1	1	to	1.2
	Trouser	1.3	to	1	1	to	1.1
Durability	Shirt	1	to	1	1	to	1
	Trouser	1	to	1	1	to	1
Heat Protection		1	to	1	1	to	1
Preference		3.2	to	1	1.3	to	1

PHYSIOLOGICAL EVALUATION

INTRODUCTION

The physiological evaluation included the testing of the cotton and LW and HW Kynol/Nomex uniforms under three environmental conditions to determine the relative heat stress imposed by the uniforms.

The heat stress imposed by the test uniforms was evaluated by comparing the cotton uniform to the two Kynol/Nomex uniforms. Comparisons were made in three environments: 70°F, 50% RH; 95°F, 70% RH, and 120°F, 20% RH. The average work load was 232 watts/m^2 and represented a moderate work activity.

PROCEDURES/RESULTS

For full details on procedures and results see Tab C.

CONCLUSIONS

1. No significant differences in tolerance time, rectal temperature, skin temperature, heart rate, evaporation rate and sweat rate were found among the three uniforms. In the hot-humid environment (95°F, 70% RH) a significantly higher evaporation/sweat ratio was found for the Kynol/Nomex uniforms (.50) as compared to the FRT cotton uniform (.41). This ratio gives some indication of the water vapor permeability of the garment to total sweat production. The Kynol/Nomex uniforms were more efficient than the cotton uniform in this respect. The higher moisture retention of the cotton fabrics contributed to this difference.

2. Ratings of the garments were also obtained from the subjective comments of the test volunteers. The test volunteers found the cotton uniform to be the most comfortable, followed by the LW Kynol/Nomex uniform. The HW Kynol/Nomex uniform was disliked by all the test volunteers.

For further information see Tab C.

HEAT PROTECTION

INTRODUCTION

The heat resistance and protection characteristics of the Kynol/Nomex blend materials were evaluated and compared to the cotton materials. The materials evaluated are shown in Table I and their application in uniform components is also indicated. Tests were conducted on the materials alone and in a garment configuration.

In studying the heat resistance and protection provided by these materials and uniforms the following information was determined:

a. Vertical flammability resistance of materials before and after laundering

b. Char through times at different radiant heat flux levels

c. Heat protection provided by the materials expressed as time to burn injury (second degree blister level burns) in:

   (1) Radiant heat exposures

   (2) Flame impingement exposures

d. Total heat protection provided by the materials in a uniform design (shirt/trouser) in a total fire envelopment situation (fire pit) for:

   (1) 0% body area second degree blister level burn injury

   (2) 20% body area second degree blister level burn injury

e. Heat protection provided by the materials in a uniform design (shirt/trouser) in a close proximity exposure to a 1500°F-2200°F fuel fire at distances of 10 and 20 feet from the fire expressed as:

   (1) Total heat protection at 0% body area second degree blister level burn injury

   (2) Percent body area which sustained second degree blister level burn injury at a total heat of 10 g cal/cm^2

   (3) Percent body area which sustained second degree blister level burn injury at 100 seconds

PROCEDURES

Vertical Flammability Resistance of Materials Before and After Laundering

To determine vertical flammability resistance Method 5903, Federal Test Method Standard 191 was employed. Data on after flame time, after glow time, and char length were obtained. Five determinations were made for each material and the results averaged. The materials were tested new and after 15 simulated shipboard launderings using Standard Navy Wash Formula II.

Char Through Times of Materials Exposed to Different Radiant Heat Flux Levels

In this experiment the materials were subjected to radiant heat flux levels ranging from 0.3 to 1.0 g cal/cm^2/sec until failure occurred or for a maximum of 120 seconds. Five specimens of each material were evaluated and the results averaged. Char through was judged by applying a small amount of pressure at the center backside of the specimen with a pencil eraser for the entire test period. The time when the pencil eraser penetrated the fabric because of significant material strength loss was recorded as char through.

For details on the apparatus employed see Tab D.

Heat Protection Provided by Materials Expressed as Time to Burn Injury (Second Degree Blister Level Burns)

Laboratory bench tests were performed to determine the protection times provided by the materials for radiant and flame impingement exposures.

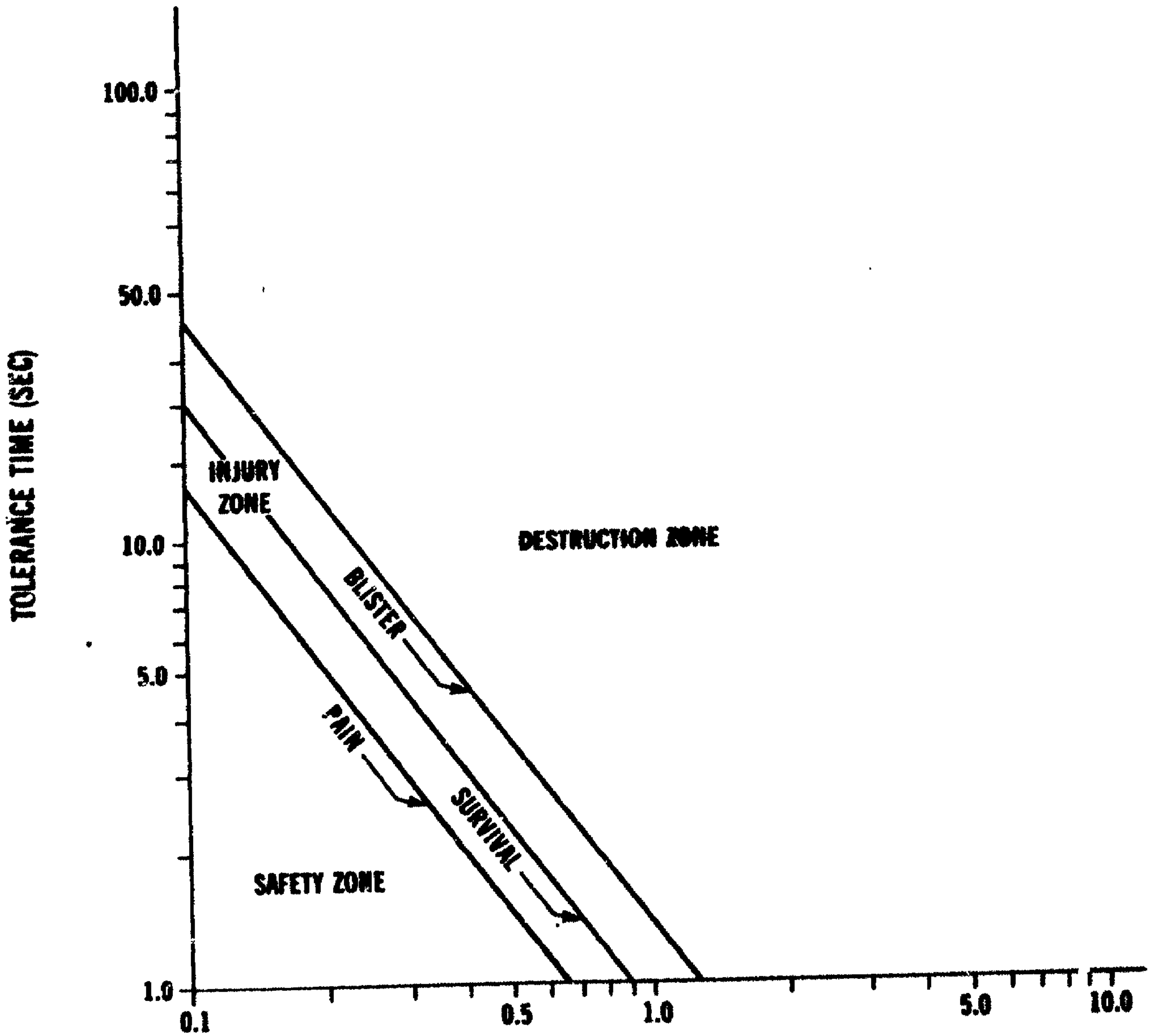
Radiant Heat Exposures

The apparatus employed was the same as used in the char through tests. The materials were exposed to three different calibrated radiant heat flux levels. The radiant flux levels chosen were equivalent to those measured in reference 1 upwind from the edge of a 20 foot diameter fuel fire at distances of 4 feet (0.5 g cal/cm^2/sec), 16 feet (0.3 g cal/cm^2/sec) and 36 feet (0.1 g cal/cm^2/sec).

A Medtherm Corporation water cooled heat flux transducer was located behind the fabric specimens to measure the heat transmitted through the fabrics. Data were obtained with the heat flux transducer directly against the fabric and at a distance of one-half inch behind the fabric. Data from five samples of each fabric were averaged and reported. The measured heat flux transmitted through the fabric was converted to burn time estimations using burn data developed by Stoll and Chianta, Naval Air Development Center (Fig. 4 and ref. 2).

FIGURE 4.

EVALUATION OF THERMAL PROTECTION STOLL AND CHIANTA



HUMAN SKIN TOLERANCE TIME TO ABSORBED THERMAL ENERGY DELIVERED IN A RECTANGULAR HEAT PULSE.

Flame Impingement Exposures

The apparatus employed was similar in construction to that developed by Stoll and Chianta, Naval Air Development Center, and described in reference 3. The materials were exposed in a horizontal position using a propane gas fueled Meker burner as the heat source. The heat source was calibrated with a Hy Cal Engineering Co. water cooled heat flux transducer at a flux level of 2.0 g cal/cm^2/sec. This flux level is generally accepted as average for a large fuel fire. An Albany International Research Corporation skin simulant sensor was located in direct contact with the rear of the fabric to measure the heat transmitted through the fabric. As in the radiant tests, time to burn injury (second degree blister level burns) was estimated from burn data developed by Stoll and Chianta (Fig. 4). The average results from three samples of each fabric were reported.

Flame Envelopment Tests

Fire pit tests were conducted at the Naval Air Development Center (NADC), Warminster, PA to determine the degree of fire protection provided by the Kynol/Nomex and cotton materials in a utility uniform configuration identical in design to the Navy's standard utility uniform.

In these tests three Kynol/Nomex blend fabrics in two uniform combinations consisting of a shirt and trouser, and one cotton two piece uniform consisting of a chambray shirt and a denim trouser were evaluated. The weights and construction of the fabrics used in these uniforms are shown in Table XI. The fire exposure time was two seconds, which was based on the Navy Decision Coordinating Paper (NDCP) No. S-1121-OL, April 29, 1980 protection requirement for shipboard utility uniforms.

TABLE XI - CHARACTERISTICS OF FR UTILITY UNIFORMS

Component	Material	Construction	Weight (oz/yd^2)
FRT Cotton			
Shirt	100% FRT Cotton	Chambray	6.5
Trouser	100% FRT Cotton	Denim	12.0
Lightweight Kynol/Nomex			
Shirt	70/30% Kynol/Nomex	Plain Weave	4.5
Trouser	70/30% Kynol/Nomex	Plain Weave	6.0
Heavyweight Kynol/Nomex			
Shirt	70/30% Kynol/Nomex	Plain Weave	6.0
Trouser	80/20% Kynol/Nomex	Twill	8.0

The fuel fire pit facility employs a rotary crane to carry a dressed manikin through the flames. The rotation of the crane was adjusted so that the manikin was engulfed in the flames for two seconds. For a description of the fire pit facility see Tab D.

Fiberglass manikins coated with a fire retardant paint were employed in these tests. The manikins were equipped with leather patches at 26 discrete body sites in the torso, leg, and arm areas (Fig. 5 and Table XII). Affixed to each leather patch was a set of seven temperature sensitive tapes each measuring approximately 5/16 x 1-7/8 inches. Each tape was stamped with its activation temperature value. When a tape reaches its activation temperature it changes shade permanently from grey to black. The activation temperature of each set ranged from 220°F to 280°F in increments of 10°F. The response of the tape and leather patch assemblies had been precalibrated to equate to burn injury levels established by Stoll and Chianta (Fig. 4).

To calibrate the tape leather patch assemblies to the Stoll-Chianta burn injury curves, the quartz lamp radiant heat tester used in the char through and radiant heat tests was employed. A Medtherm water cooled heat flux transducer was initially placed behind a single layer of fabric and the radiant heat load incident on the fabric was increased in discrete increments for exposures of two seconds until the heat flux measurements behind the test fabric were equivalent to the pain, survival, and blister levels shown in Fig. 4 for a two second exposure. The heat flux transducer was then replaced by the tape-leather patch assemblies. Employing the same radiant heat loads, and 2 second exposures used to determine pain to blister levels with the heat flux transducer, the highest tape activation temperature for each of these conditions was noted and is shown in Table XIII. The percentage body burn area was estimated from those tapes that activated at 280°F (second degree blister level burn).

The test manikins instrumented with the paper tape-leather patch assemblies were dressed with underwear consisting of a t-shirt and boxer shorts, calf length wool blend socks, chukka boots, and the particular test garment employed. The dressed manikin was then mounted to the crane manikin carry frame equipped with a HyCal Engineering Corporation water cooled heat flux transducer to measure the heat load of the fire and isolated from the fire pit behind a cement block wall.

Water and then JP-5 fuel were introduced into the pit and the JP-5 fuel was then ignited and allowed to preburn until the fire was fully developed. The crane was then energized and the manikin directed through the fire and de-energized when the manikin appeared behind the cement block wall. During the period of exposure the output of the heat flux transducer attached to the manikin carry frame was measured with a millivolt recorder. Movie cameras were placed to monitor the manikin emerging from the flames so that the time of any after flame condition could be determined.

After completion of a series of tests the manikins were undressed and the temperatures of the activated tapes were noted at each location on the manikin surface and total heat exposure of the manikin for each test was determined by integrating the heat flux transducer output. The activation temperature of the tapes was then translated to percent burn injury area for each exposure and related to the total heat exposure obtained from the heat flux data.

Test garments were evaluated both in a new condition and after being subjected to 15 simulated shipboard launderings using Navy Shipboard Wash Formula II. The number of tests conducted on each of the test garments in both the new and laundered state are shown in Table XIV.

Because of the variation in the heat exposure and burn injury measurements between tests on each garment, a linear regression analysis was performed on the test data to establish the relationship between total heat of exposure and extent of burn injury for each type of test garment.

TABLE XII - SENSOR SITES

1. UT2F Upper Torso 2 Front
2. UT2B Upper Torso 2 Back
3. UT3F Upper Torso 3 Front
4. UT3B Upper Torso 3 Back
5. UT6F Upper Torso 6 Front
6. UT6B Upper Torso 6 Back
7. LT1F Lower Torso 1 Front
8. LT1B Lower Torso 1 Back
9. LT2F Lower Torso 2 Front
10. LT2B Lower Torso 2 Back
11. RA3FU Right Arm 2 Front UP
12. RA2FD Right Arm 2 Front Down
13. RA2BU Right Arm 2 Back Up
14. RA2BD Right Arm 2 Back Down
15. LA2FU Left Arm 2 Front Up
16. LA2FD Left Arm 2 Front Down
17. LA2BU Left Arm 2 Back Up
18. LA2BD Left Arm 2 Back Down
19. RL1F Right Leg 1 Front
20. RL1B Right Leg 1 Back
21. RL3F Right Leg 3 Front
22. RL3B Right Leg 3 Back
23. LL1F Left Leg 1 Front
24. LL1B Left Leg 1 Back
25. LL3F Left Leg 3 Front
26. LL3B Left Leg 3 Back

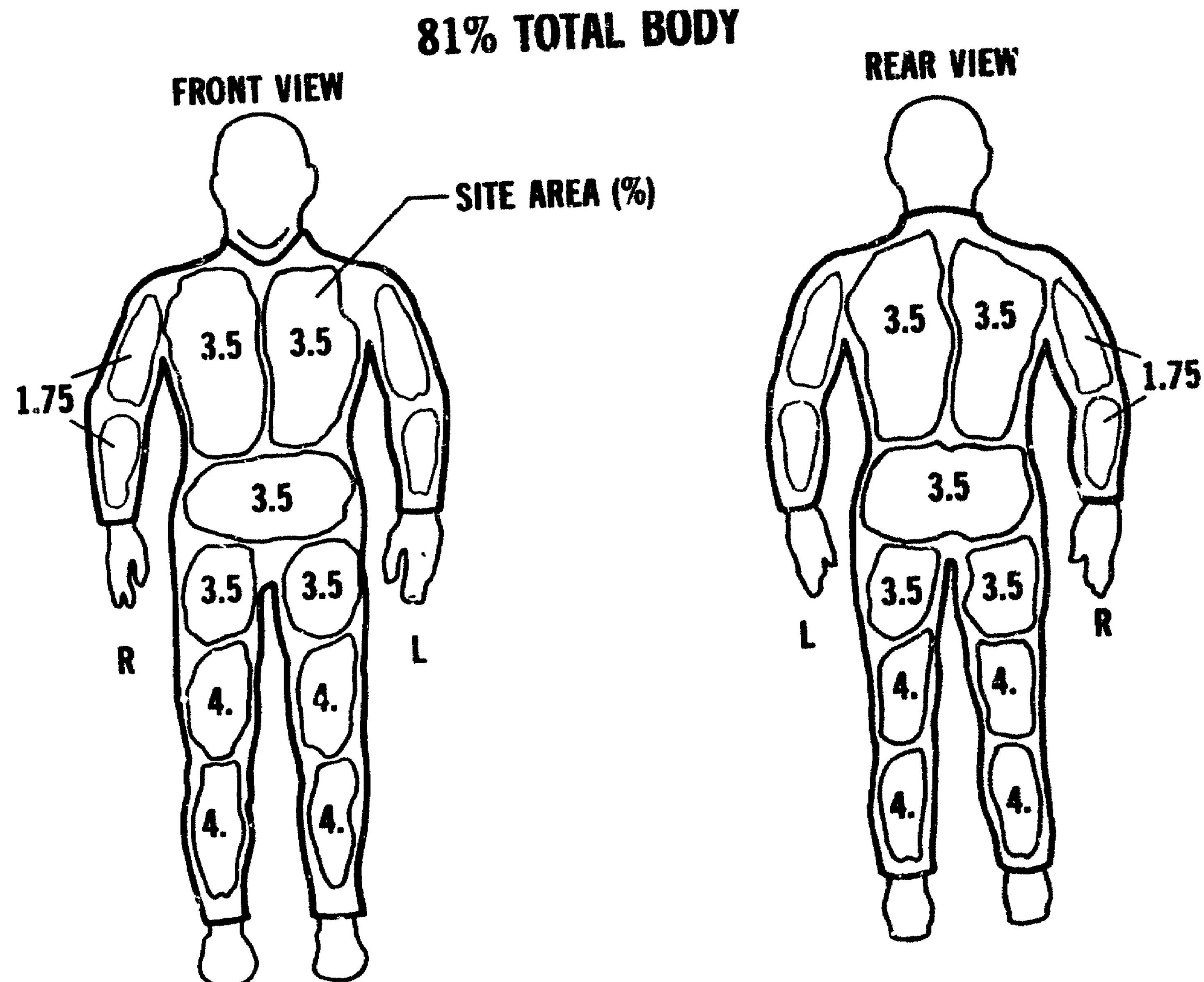


FIGURE 5. MANIKIN PAPER TAPE TEMPERATURE SENSOR SITES

TABLE XIII - RELATIONSHIP OF BURN LEVEL TO PAPER TAPE ACTIVATION TEMPERATURE

Degree of Burn Injury	Paper Tape Temp (^{o}F)*
Pain	240
Survival	260
Blister	280

* Body burn area was calculated for a tape activation temperature of 280^{o}F.

TABLE XIV NUMBER OF TEST GARMENTS OF EACH TYPE EVALUATED IN A NEW AND LAUNDERED CONDITION

Test Garments	Condition	Number Tested
FRT Cotton	New	10
	Laundered	10
Lightweight Kynol/Nomex	New	10
	Laundered	10
Heavyweight Kynol/Nomex	New	10
	Laundered	10

Fire Exposure Protection in Close Proximity to the Fire Pit

The fire proximity exposure tests were conducted simultaneously with the fire entry tests with an instrumented manikin dressed in the test clothing placed at distances of 10 and 20 feet from the fire. Data relating the burn injury protection of each of the uniforms to this exposure were established.

A fiberglass manikin instrumented with twenty heat flux transducers was used to determine the resulting burn injury. Although the manikin contained 20 sensors, only those covered by the test uniform were used to calculate the percent body burn area. This area represented 81% of the total body area and involved 16 of the 20 heat flux transducers. The hands, head, and feet were omitted from the total calculation. Table XV lists the location and percent body area represented by each sensor. Figure 6 illustrates the percent body area covered by each. A heat flux transducer and radiometer were mounted at waist level on a frame used to support the manikin to record both the incident radiant and total heat flux of the fire on the dressed manikin surface. A Hewlett Packard data acquisition system was used to measure the heat flux levels and to convert the data to estimated TBI values using the criteria shown in Fig. 4.

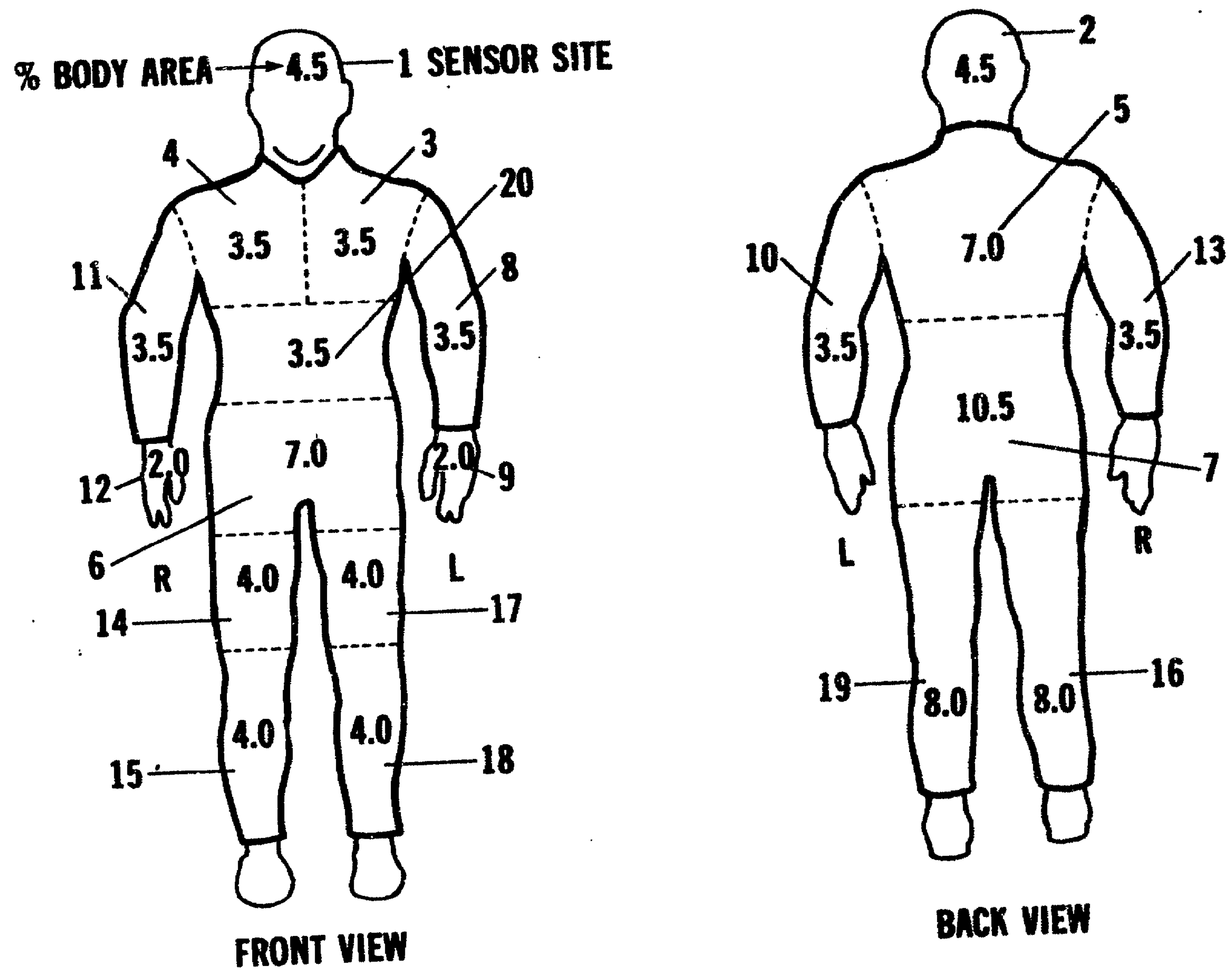
The burn injury data obtained with the instrumented manikin at ten and twenty feet were analyzed in the following way. At a total exposure time of 100 seconds the percent body burn area was calculated. Initially the heat flux data obtained by each of the heat flux transducers was recorded. This heat flux data was then converted to a total heat value (cal/cm^2) for the 100 second duration. This information was then compared to burn injury data plotted on a time versus total heat energy basis for a second degree blister level burn using the criteria in Fig. 4.

The characteristics of the uniforms tested were identical to those used in the flame envelopment tests (Table XI). Each uniform was exposed to several test fires at distances of 10 and 20 feet from the fire. However, because of the low levels of incident heat produced by some of the fires, only five test runs representing the worst burn conditions for each uniform were selected for data analysis.

TABLE XV
MANIKIN SENSOR SITES

Sensor	Location	% Body Area
1	Forehead	Not Included
2	Back of Head	Not Included
3	Left Breast	3.5
4	Right Breast	3.5
5	Middle Back	7.0
6	Front Groin	7.0
7	Lower Back	10.5
8	Front Lower Arm Left	3.5
9	Left Hand	Not Included
10	Back Upper Arm Left	3.5
11	Front Lower Arm Right	3.5
12	Right Hand	Not Included
13	Back Upper Arm Right	3.5
14	Right Leg Front Thigh	4.0
15	Right Leg Shin	4.0
16	Right Leg Calf	8.0
17	Left Leg Front Thigh	4.0
18	Left Leg Shin	4.0
19	Left Leg Calf	8.0
20	Stomach	3.5
	Total	81.0

Figure 6.
INSTRUMENTED MANIKIN



RESULTS

Vertical Flammability Resistance of Materials Before and After Laundering

As can be seen in Table XVI all the materials showed excellent vertical flammability resistance both new and after 15 simulated shipboard launderings. Maximum average char lengths measured were 3.5 inches for the Kynol/Nomex materials and 3.3 inches for the cotton materials.

TABLE XVI VERTICAL FLAMMABILITY PERFORMANCE OF FABRICS BEFORE AND AFTER SIMULATED SHIPBOARD LAUNDERINGS

	New			15 Launderings		
Material	After Flame (sec)	After Glow (sec)	Char Length (in)	After Flame (sec)	After Glow (sec)	Char Length (in)
70%/30% Kynol/Nomex 4.5 oz/yd^2	0	1	3.5	0	1	2.9
70%/30% Kynol/Nomex 6.0 oz/yd^2	0	1	3.5	0	1	2.3
80%/20% Kynol/Nomex 8.0 oz/yd^2	0	2	3.4	0	1	2.8
FRT 100% Cotton 6.5 oz/yd^2	0	1	3.2	0	1	3.3
FRT 100% Cotton 12.0 oz/yd^2	0	1	2.9	0	1	3.0

Char Through Times of Materials Exposed to Different Radiant Heat Flux Levels

Table XVII shows the char through times obtained with the various fabrics. At a flux of 0.3 g cal/cm^2/sec none of the fabrics showed char through after 120 seconds At 0.5 g cal/cm^2/sec the cotton materials began to show char through. The longer char through time for the lighter weight cotton fabric versus the heavier cotton fabric (105 sec versus 45 sec) can be attributed to color. The lighter weight cotton was light blue versus dark blue for the heavier cotton fabric (Table I). The lighter colored fabric is a more effective reflector of the radiant heat than the dark colored fabric until the front surface of the material begins to char. At 0.8 g cal/cm^2/sec the heavier Kynol/Nomex material showed char through at 110 seconds. The cotton fabrics at this flux showed significantly lower and similar char through times (21 and 19 seconds) than the Kynol/Nomex materials. At 1.0 g cal/cm^2/sec all fabrics showed char through below 120 seconds. The two higher Nomex blended Kynol fabrics showed greater char through times than the lower Nomex blended Kynol material. Similar to the other flux levels, all the Kynol/Nomex fabrics showed significantly higher char through times than the cotton fabrics which behaved similarly.

The data indicates that the Kynol/Nomex fabrics have greater heat resistance to degradation than the cotton fabrics. Higher percentages of Nomex in the blended Kynol fabrics appeared to improve the heat resistance of these fabrics. For the two Kynol/Nomex fabrics blended similarly, the heavier weight fabric took longer to char through.

TABLE XVII CHAR THROUGH TIMES AT DIFFERENT RADIANT HEAT FLUX LEVELS

Fabric	Weight (oz/yd^2)	Radiant Heat Flux (g cal/cm^2/sec)			
		0.3	0.5	0.8	1.0
70/30% Kynol/Nomex	4.5	NC	NC	NC	34
70/30% Kynol/Nomex	6.0	NC	NC	NC	38
80/20% Kynol/Nomex	8.0	NC	NC	110	29
FRT 100% Cotton	6.5	NC	105	21	10
FRT 100% Cotton	12.0	NC	45	19	11

NC = No char through up to 120 seconds

Heat Protection Provided by Materials Expressed as Time to Burn Injury (Second Degree Blister Level Burns)

Radiant Heat Exposures

Table XVIII shows the TBI data for the materials exposed to different radiant heat flux levels with the heat flux transducer in contact with the materials. At each flux level, the cotton materials showed higher TBIs than any of the Kynol/Nomex fabrics. For the most part, the TBI values were directly related to the weight of the fabrics regardless of the material type (greater weight-higher TBI) except for the lightweight cotton fabric which showed better performance for its weight than the other materials. This was attributed to the color of this fabric which was lighter than the others and more efficient in reflecting the radiant heat. The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton materials. Weight of the fabric was more a measure of protection time achieved than other material properties.

In comparing Table XVIII data to Table XVII (Char Through Times), it can be seen that burns would be sustained at comparable heat flux levels with both the Kynol/Nomex and cotton fabrics long before significant material damage would occur with the cotton materials negating to some degree the benefit derived from using the higher heat resistant Kynol/Nomex fabrics.

TABLE XVIII ESTIMATED TIME TO BURN INJURY (TBI) WITH THE HEAT FLUX SENSOR IN CONTACT WITH THE MATERIALS

Heat Flux (g cal/cm^2/sec)	Material	Weight (oz/yd^2)	TBI (sec)
0.5	70/30% Kynol/Nomex	4.5	10
	70/30% Kynol/Nomex	6.0	10
	80/20% Kynol/Nomex	8.0	13
	FRT 100% Cotton Chambray	6.5	15
	FRT 100% Cotton Denim	12.0	20
0.3	70/30% Kynol/Nomex	4.5	17
	70/30% Kynol/Nomex	6.0	18
	80/20% Kynol/Nomex	8.0	20
	FRT 100% Cotton Chambray	6.5	25
	FRT 100% Cotton Denim	12.0	33
0.1	70/30% Kynol/Nomex	4.5	67
	70/30% Kynol/Nomex	6.0	70
	80/20% Kynol/Nomex	8.0	72
	FRT 100% Cotton Chambray	6.5	78
	FRT 100% Cotton Denim	12.0	100

Table XIX shows the data for exposures to different radiant heat flux levels with the heat flux transducer one-half inch away from the materials. The characteristics of the data were similar to the contact case (Table XVIII) in that the heavier the material the greater the TBI except there were no exceptions to this relationship in these tests. With the sensor not in contact with the fabric, the TBIs for any particular fabric and test condition were at least twice as long with respect to the fabric contact case. As indicated for the contact case the Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton fabrics. The weight of the material was more indicative of potential protection time than any other material property for either material type.

As in the contact case burns would have occurred with the Kynol/Nomex fabrics long before any significant fabric damage (char through) would have happened (Table XVII) with the cotton fabrics negating to some degree the benefit of using the higher heat resistant Kynol/Nomex fabrics. For the 0.5 $gcal/cm^2/sec$ flux level, the heavier cotton fabric had a TBI essentially equivalent to its char through time at this flux (43 versus 45 sec).

TABLE XIX ESTIMATED TIME TO BURN INJURY (TBI)
WITH THE HEAT FLUX TRANSDUCER 1/2 INCH IN BACK OF THE MATERIALS

Heat Flux ($g\ cal/cm^2/sec$)	Material	Weight (oz/yd^2)	TBI (sec)
0.5	70/30% Kynol/Nomex	4.5	21
	70/30% Kynol/Nomex	6.0	27
	80/20% Kynol/Nomex	8.0	33
	FRT 100% Cotton Chambray	6.5	30
	FRT 100% Cotton Denim	12.0	43
0.3	70/30% Kynol/Nomex	4.5	42
	70/30% Kynol/Nomex	6.0	53
	80/20% Kynol/Nomex	8.0	63
	FRT 100% Cotton Chambray	6.5	60
	FRT 100% Cotton Denim	12.0	87
0.1	70/30% Kynol/Nomex	4.5	>100
	70/30% Kynol/Nomex	6.0	>100
	80/20% Kynol/Nomex	8.0	>100
	FRT 100% Cotton Chambray	6.5	>100
	FRT 100% Cotton Denim	12.0	>100

Flame Impingement Exposures

Table XX shows the estimated TBI data when the materials were subjected to a direct flame exposure at a heat flux level of 2.0 g cal/cm^2/sec with the skin sensor in contact with the materials. As can be seen the TBI data can be correlated to the weight of the fabrics rather than the fiber content of the materials. Considering the Kynol/Nomex fabrics, the lighter 4.5 oz/yd^2 fabric had a 2.2 second TBI while the heavier 8.0 oz/yd^2 fabric had a 4.3 second TBI. For the cotton fabrics, the lighter 6.5 oz/yd^2 fabric had a TBI of 3.9 seconds and the heavier 12 oz/yd^2 fabric had a TBI of 6.4 seconds. As indicated in the radiant heat tests the Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton fabrics. The weight of the materials was more indicative of potential protection time than any other material property for either material type.

TABLE XX ESTIMATED TIME TO BURN INJURY (TBI)
FLAME IMPINGEMENT - HEAT FLUX 2.0 G CAL/CM^2/SEC

Material	Weight (oz/yd^2)	TBI (Sec)
70/30% Kynol/Nomex	4.5	2.2
70/30% Kynol/Nomex	6.0	3.0
80/20% Kynol/Nomex	8.0	4.3
FRT 100% Cotton Chambray	6.5	3.9
FRT 100% Cotton Denim	12.0	6.4

Flame Envelopment Tests

Individual Test Results

Cotton Uniform (Table XXI)

New Condition - Total heat from the 10 exposures conducted ranged from 2.4 to 9.7 gcal/cm^2 and burn injury area estimates ranged from 0 to 14 percent. The average total heat was 5.4 $\pm$ 2.4 gcal/cm^2 and the average estimated burn injury area was 5 $\pm$ 4 percent.

Laundered - Total heat from the 10 exposures conducted ranged from 2.4 to 9.6 gcal/cm^2 and burn injury area estimates ranged from 0 to 9 percent. The average total heat was 5.1 $\pm$ 2.3 gcal/cm^2 and the average estimated burn injury was 3 $\pm$ 3 percent.

Lightweight Kynol/Nomex Uniform (Table XXI)

<u>New Condition</u> - Total heat from the 10 exposures conducted ranged from 1.4 to 8.6 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 22 percent. The average total heat was 4.8 $\pm$ 2.3 $gcal/cm^2$ and the average estimated burn injury area was 9 $\pm$ 8 percent

<u>Laundered</u> - Total heat from the 10 exposures conducted ranged from 1.3 to 8.5 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 22 percent. The average total heat was 5.0 $\pm$ 2.2 $gcal/cm^2$ and the average estimated burn injury area was 7 $\pm$ 6 percent.

Heavyweight Kynol/Nomex Uniform (Table XXI)

<u>New Condition</u> - Total heat from the 10 exposures conducted ranged from 2.4 to 7.6 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 9 percent. The average total heat was 5.0 $\pm$ 1.7 $gcal/cm^2$ and the average estimated burn injury area was 4 $\pm$ 4 percent.

<u>Laundered</u> - Total heat from the 10 exposures conducted ranged from 2.4 to 7.6 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 13 percent. The average total heat was 5.0 $\pm$ 1.7 $gcal/cm^2$ and the average estimated burn injury area was 4 $\pm$ 4 percent.

TABLE XXI - INDIVIDUAL TOTAL HEAT - ESTIMATED BLISTER LEVEL BURN INJURY DATA FOR 2 SECOND - JP-5 FUEL TESTS

Condition	FRT Cotton Total Heat ($gcal/cm^2$)	FRT Cotton Body Burn (%)	Lightweight Kynol/Nomex Total Heat ($gcal/cm^2$)	Lightweight Kynol/Nomex Body Burn (%)	Heavyweight Kynol/Nomex Total Heat ($gcal/cm^2$)	Heavyweight Kynol/Nomex Body Burn (%)
New	2.4	0	1.4	0	2.4	0
	4.3	0	2.0	0	3.2	0
	3.0	2	5.3	4	4.8	0
	5.6	2	5.7	4	5.6	0
	2.0	4	3.6	4	3.2	2
	5.0	5	6.0	7	4.8	4
	7.6	5	2.6	10	6.6	4
	7.5	6	5.4	17	4.5	8
	7.1	9	7.6	19	7.6	8
	9.7	14	8.6	22	7.5	9
Average	5.4	5	4.8	9	5.0	4
	± 2.4*	± 4	± 2.3	± 8	± 1.7	± 4
15 Shipboard Launderings	2.4	0	1.3	0	2.4	0
	4.3	0	2.0	0	3.2	0
	7.4	0	5.3	4	4.8	0
	2.9	2	5.7	4	5.5	0
	5.6	2	7.5	4	3.2	2
	5.0	4	6.0	4	4.7	4
	1.9	4	5.9	7	6.5	4
	4.9	5	2.6	9	5.0	8
	7.0	5	5.3	13	7.6	8
	9.6	9	8.5	22	7.5	13
Average	5.1	3	5.0	7	5.0	4
	± 2.3	± 3	± 2.2	± 6	± 1.7	± 4

* Denotes standard deviation

Comparison of Test Garments

Linear regression curves (Fig. 7) for the new garments and for laundered garments (Fig. 8) show the extent of estimated burn injury area as a function of total heat of exposure. It is quite clear from Fig. 7 that the heavier uniforms (cotton and HW Kynol/Nomex) when new provided significantly more heat protection than the LW Kynol/Nomex uniform, and the protection provided by the cotton and HW Kynol/Nomex uniforms was similar. Fig. 8 indicates there was some protection degradation for the HW Kynol/Nomex uniform after laundering. The LW Kynol/Nomex and cotton uniforms showed improved protection after laundering. These changes after laundering were probably more related to test variability than the condition of the garments. As in the bench tests, the Kynol/Nomex uniforms showed no unique burn protection characteristics with respect to the cotton uniform, results being more associated with the weight of the garments rather than any other material property. The correlation coefficients for the curves in Fig. 7 related to a confidence level of greater than 95%. For the Fig. 8 curves, the confidence level was at least 90%.

Significance of Burn Injury

According to the Standard First Aid Training Course Manual NAVEDTRA 10081-N (ref 4), burns involving more than 20 percent of the skin surface area endanger life and 30 percent burns are usually fatal if adequate medical treatment is not received. The U.S. Army and Air Force when estimating the total heat protection provided by a particular uniform for tank and air crews uses 20 percent body burn area as the cutoff criteria. Using this 20 percent criteria one can estimate the total heat protection provided by a garment at a level that would not endanger life. Considering this criteria and using the linear regression curves in Fig. 7 the LW Kynol/Nomex uniform new would require a total heat exposure of 8.8 g cal/cm^2 for a 20% body area blister level burn to occur. The burn area for the HW Kynol/Nomex and the cotton uniforms new was well below the 20% body burn cutoff criteria in all tests. For a total heat of 8.8 g cal/cm^2 the estimated body area blister level burns were 8.5% and 9.3% for the HW Kynol/Nomex and cotton uniforms, respectively.

As shown in Fig. 8, once laundered the burn area for the LW Kynol/Nomex uniform fell below the 20% body burn area cutoff criteria with an estimated body burn area of 13.5 percent at a total heat of 10.0 g cal/cm^2. The burn area for the laundered HW Kynol/Nomex and FRT cotton uniforms at the 10.0 g cal/cm^2 total heat level was 12% and 6%, respectively.

The estimated total heat protection provided before any second degree level burn is reached can be estimated from the linear regression curves (Fig 7 & 8). Considering new garments a total heat exposure of 1.6 g cal/cm^2 for the LW Kynol/Nomex uniform, 2.2 gcal/cm^2 for cotton uniform, and 2.5 g cal/cm^2 for the HW Kynol/Nomex uniform would be required before a second degree burn would be sustained. After laundering these estimates were 1.0 g cal/cm^2 for the LW Kynol/Nomex and cotton uniforms, and 3.0 g cal/cm^2 for the HW Kynol/Nomex uniform.

FIGURE 7.
PERCENT BODY BURN VS TOTAL HEAT (CAL./SQ. CM)
FLAME ENVELOPMENT - NEW GARMENTS

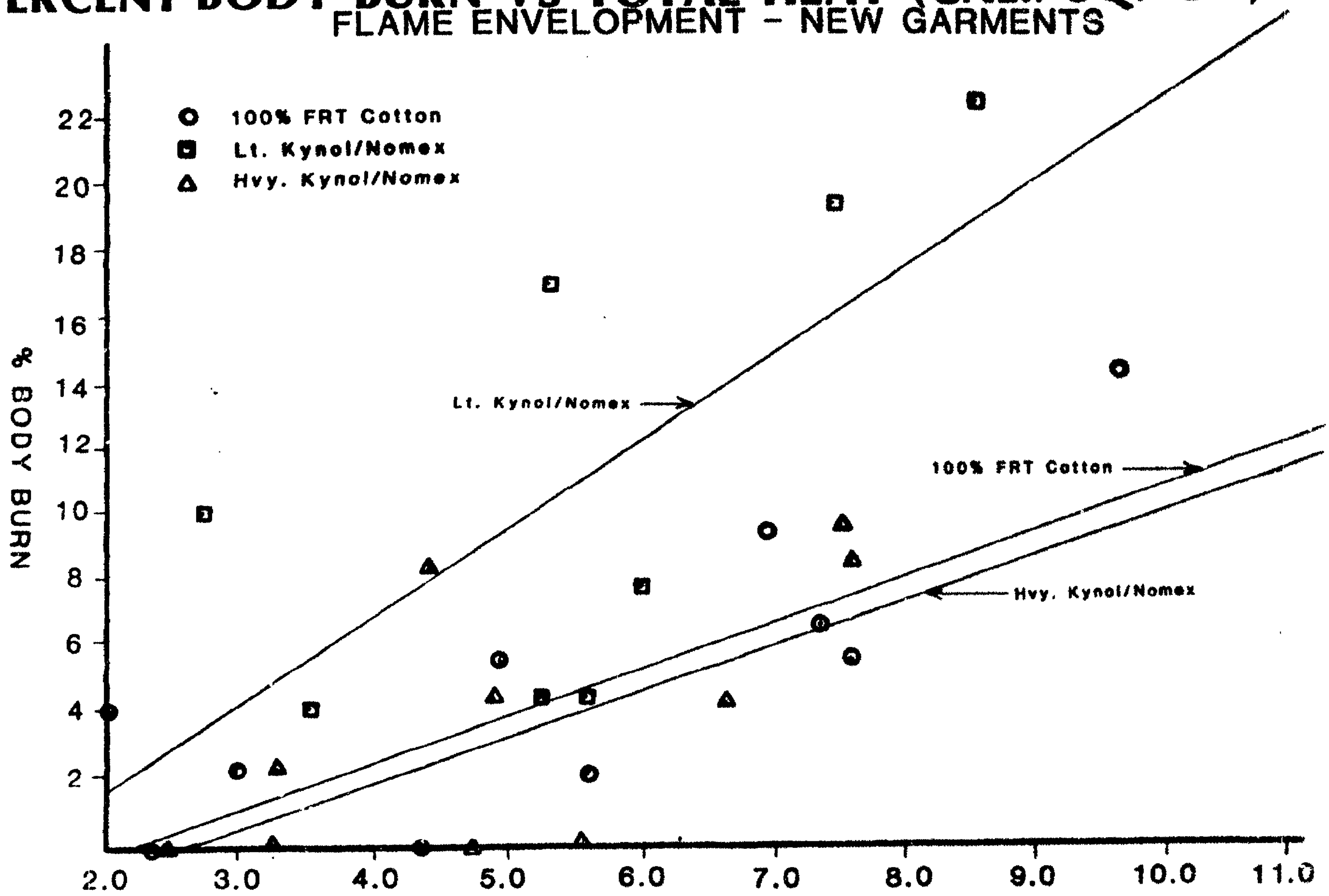
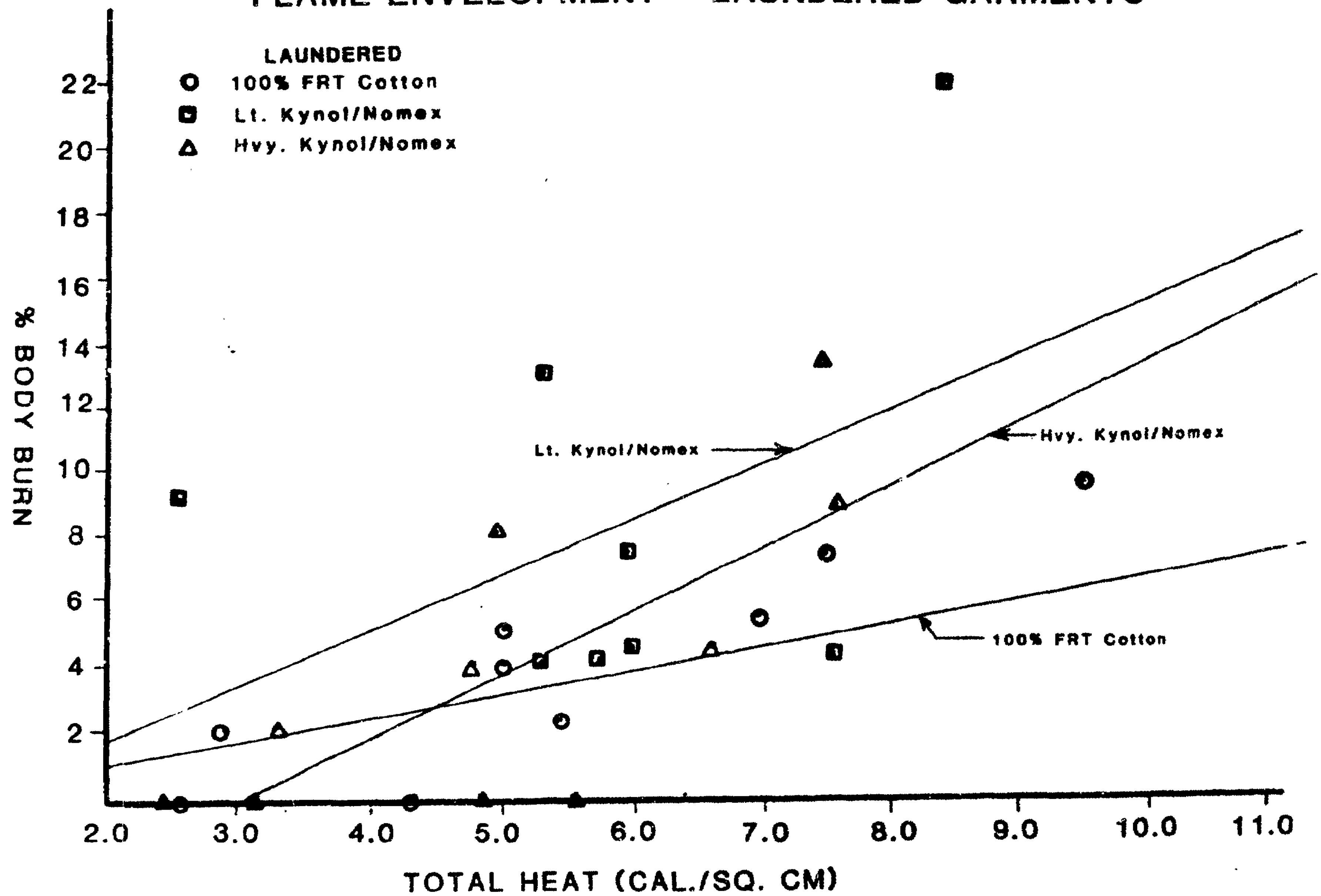


FIGURE 8.

PERCENT BODY BURN VS TOTAL HEAT (CAL./SQ. CM)

FLAME ENVELOPMENT – LAUNDERED GARMENTS



In these studies the cotton and the HW Kynol/Nomex uniforms in a new condition were equivalent in protection and significantly more protective than the LW Kynol/Nomex uniform. Differences in performance between the new and laundered conditions for the different type uniforms were believed to be more related to the variability associated with these types of tests than any changes in the materials as a result of laundering.

Fire Exposure Protection in Close Proximity to the Fire Pit

Individual Test Results

Lightweight Kynol/Nomex Uniform

Five test runs were analyzed with the manikin at a distance of ten feet from the fire. Table XXII illustrates the total and radiant heat loads generated by each fire after 100 seconds and the percent body burn area sustained. The average total heat of the fires was 11.9 g cal/cm^2, with 9.2 g cal/cm^2 attributed to radiant heat. Based on the average heat exposure burn injury occurred over 9% of the covered body area. Among the five test runs conducted the highest total heat level recorded was 25.5 g cal/cm^2 (19.4 g cal/cm^2 radiant). At this level the body burn area was 29%, 21% on the upper body and 8% on the lower body.

TABLE XXII HEAT LOAD AND BURN DATA
FOR LIGHTWEIGHT KYNOL/NOMEX UNIFORM
AT 10 FEET FROM FIRE AFTER 100 SECONDS EXPOSURE

Total Heat (g cal/cm^2)	Radiant Heat (g cal/cm^2)	Body Burn (%)
25.5	19.4	29
9.1	7.1	4
8.6	6.8	0
8.5	6.7	8
8.2	6.3	4
11.9 $\pm$ 6.8*	9.2 $\pm$ 5.1	9 $\pm$ 10.3

*Denotes standard deviation.

Five test runs were also conducted with the manikin at a distance of 20 feet from the fire. Table XXIII lists the total and radiant heat loads generated by each fire and the percent body burn area suffered. The average total heat of the fires recorded at this distance was 7.0 g cal/cm^2, 5.4 g cal/cm^2 attributed to radiant heat. Based on the average heat exposure a 3.8% body burn area was sustained on the covered body area. Among the five test runs conducted the highest recorded total heat was 12.1 g cal/cm^2, 9.3 g cal/cm^2 attributed to radiant heat. For this fire, the body burn area was 15%, 7% on the upper body and 8% on the lower body.

TABLE XXIII HEAT LOADS AND BURN DATA FOR LIGHTWEIGHT KYNOL/NOMEX UNIFORM AT 20 FEET FROM FIRE AFTER 100 SECONDS EXPOSURE

Total Heat (g cal/cm^2)	Radiant Heat (g cal/cm^2)	Body Burn (%)
12.1	9.3	15
7.6	5.8	4
6.4	5.6	0
5.0	3.8	0
4.1	3.2	0
7.0 $\pm$ 2.8*	5.4 $\pm$ 2.2	3.8 $\pm$ 5.8

* Denotes standard deviation.

Heavyweight Kynol/Nomex Uniform

Five test runs were analyzed with the manikin at a distance of ten feet from the fire. Table XXIV lists the total and radiant heat levels generated by each fire along with the percent body burn area suffered. The average total heat generated by the fires at this distance was 12.9 g cal/cm^2, 10.1 g cal/cm^2 attributed to radiant heat. Based on the average heat exposure the body burn area was 4.6% of the covered body area. Among the five test runs conducted the highest total heat registered was 22.0 g cal/cm^2, 17.6 g cal/cm^2 attributed to radiant heat. For this fire the body burn area was 15%, 7.0% on the upper body and 8.0% on the lower body.

TABLE XXIV HEAT LOAD AND BURN DATA FOR HEAVYWEIGHT KYNOL/NOMEX UNIFORM AT 10 FEET FROM FIRE AFTER 100 SECONDS EXPOSURE

Total Heat ($g\ cal/cm^2$)	Radiant Heat ($g\ cal/cm^2$)	Body Burn (%)
22.0	17.6	15
13.7	11.0	4
12.7	9.8	4
9.0	6.9	0
6.9	5.1	0
12.9 ± 5.2	10.1 ± 4.3	4.6 ± 5.5

* Denotes standard deviation

Five test runs were also analyzed with the manikin at a distance of 20 feet from the fire. Table XXV lists the total and radiant heat levels generated by each fire along with the body burn area data. The average heat generated by the fires at this distance was 9.7 g cal/cm^2, 7.6 g cal/cm^2 attributed to radiant heat. Based on the average heat exposure, the body burn area was 5.6% of the covered body area. Among the five test runs conducted, the highest total heat registered was 12.8 g cal/cm^2, 10.1 g cal/cm^2 attributed to radiant heat. At this level the body burn area was 8%. None on the upper body and 8% on the lower body.

TABLE XXV HEAT LOAD AND BURN DATA FOR HEAVYWEIGHT KYNOL/NOMEX UNIFORM AT 20 FEET FROM FIRE AFTER 100 SECONDS EXPOSURE

Total Heat ($g\ cal/cm^2$)	Radiant Heat ($g\ cal/cm^2$)	Body Burn (%)
12.8	10.1	8
10.6	8.2	8
10.0	7.9	4
7.8	5.9	4
7.3	5.7	4
9.7 ± 6.7*	7.6 ± 1.6	5.6 ± 1.9

* Denotes standard deviation.

Cotton Uniform

As with both Kynol/Nomex uniforms five test runs with the cotton uniform were analyzed with the manikin at a distance of ten feet from the fire. Table XXVI lists the total and radiant heat levels generated by each fire along with the percent body burn area suffered. The average total heat generated by the fires at this distance was 5.2 g cal/cm^2, 3.8 g cal/cm^2 was attributed to radiant heat. The heat energy generated by these fires was the lowest of all the test runs and no body burns were recorded on the covered body area for 100 seconds. Even for the 9.5 g cal/cm^2 total heat fire no body burns were sustained.

TABLE XXVI HEAT LOAD AND BURN DATA FOR FRT COTTON UNIFORM AT 10 FEET FROM FIRE AFTER 100 SECONDS EXPOSURE

Total Heat (g cal/cm^2)	Radiant Heat (g cal/cm^2)	Body Burn (%)
9.5	8.0	0
7.6	5.3	0
4.5	7.0	0
3.4	2.0	0
1.2	.1	0
5.2 ± 3.0*	3.8 ± 2.6	0 ± 0

* Denotes standard deviation.

Five test runs were analyzed with the manikin at a distance of 20 feet from the fire. Table XXVII lists the total and radiant heat levels generated by each fire along with the percent body burn area suffered. Whereas the runs at ten feet registered low heat levels, the runs at 20 feet from the fire were among the highest heat levels recorded. The average heat generated by the fires at this distance was 12.1 g cal/cm^2, 9.4 g cal/cm^2 was attributed to radiant heat. Based on the average heat value the body burn area was 4.6% of the covered body area at 100 seconds. Among the five test runs conducted, the highest heat level registered was 16.6 g cal/cm^2, 13.3 g cal/cm^2 was attributed to radiant heat. For this fire the body burn area was 12% of the covered body area, 4% on the upper body and 8% on the lower body.

TABLE XXVII HEAT LOAD AND BURN DATA FOR FRT COTTON UNIFORM AT 20 FEET FROM FIRE AFTER 100 SECONDS EXPOSURE

Total Heat ($g\ cal/cm^2$)	Radiant Heat ($g\ cal/cm^2$)	Body Burn (%)
16.6	13.3	12
14.2	11.1	12
11.8	9.6	0
9.5	6.9	0
8.1	6.3	0
12.1 ± 3.1*	9.4 ± 2.6	4.6 ± 5.6

* Denotes standard deviation.

Effect of Laundering

To examine the effect of laundering on the uniforms, two test runs were performed on each uniform after the uniforms had been subjected to 15 simulated shipboard launderings. No significant differences were noted in the resulting body burn area data with respect to the new condition.

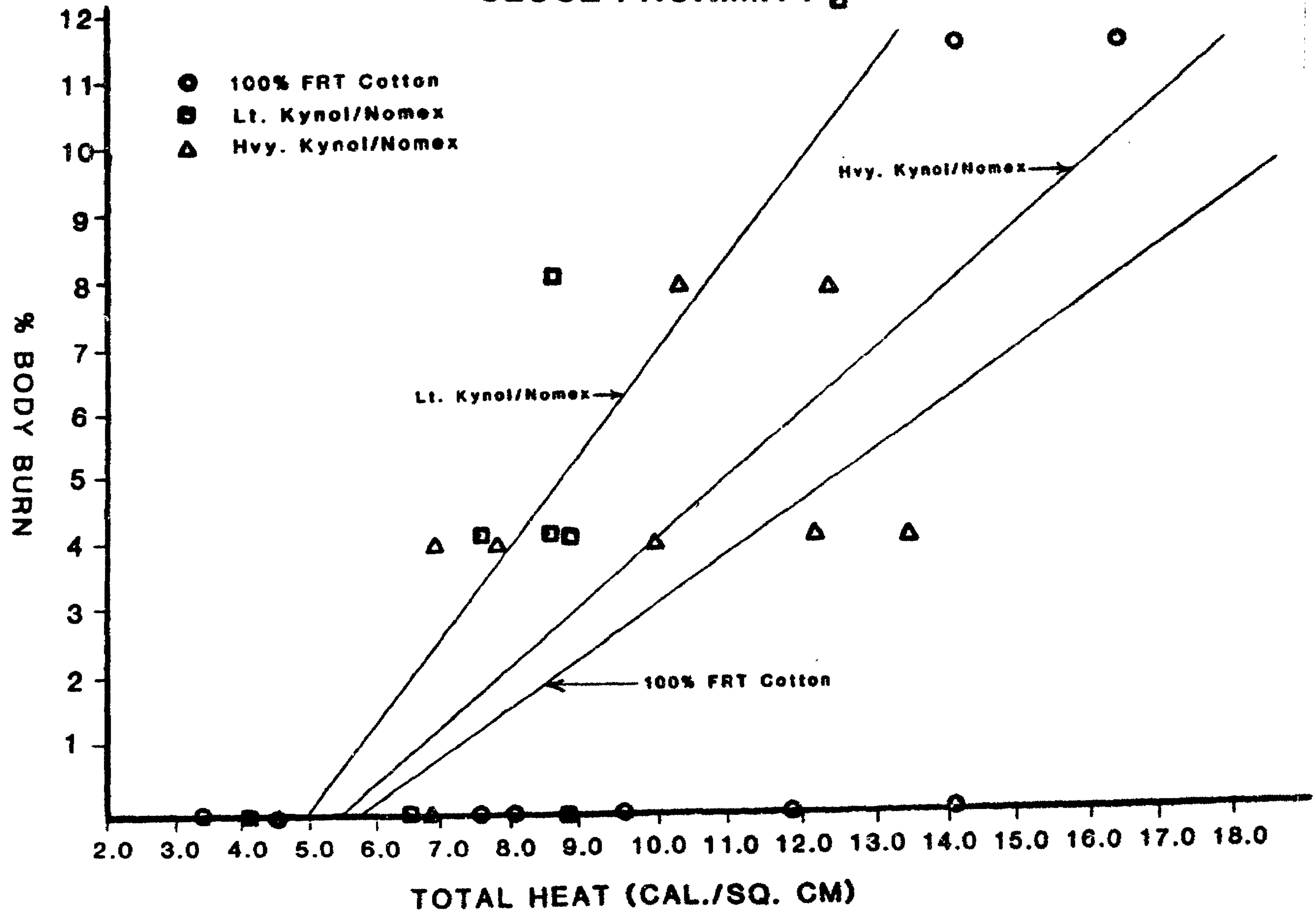
Comparison of Test Garments

Linear regression curves (Fig. 9) for each of the uniforms show the extent of the estimated burn injury area as a function of total heat exposure. Because of the variability of the fires, the total heat loads recorded were more indicative of the burn injury area than the distance from the fires. Therefore, the data from the 10 and 20 foot fires were pooled to develop the results shown in Fig. 9. It can be seen that the cotton uniform provided better heat protection for the heat range encountered than either Kynol/Nomex uniform. Both the cotton and HW Kynol/Nomex uniforms provided significantly better protection than the LW Kynol/Nomex uniform. The correlation coefficients for the curves in Fig. 9 related to a confidence level of greater than 95%.

Significance of Burn Injury

As indicated previously under the fire envelopment tests, a 20 percent body burn area is used by the services as the cutoff criteria. Considering this criteria it is quite clear from Fig. 9 that all three uniforms provided protection well below the 20% body burn area criteria at the total heat levels encountered. At a total heat level of 10.0 g cal/cm^2 the body burn area measured for the LW Kynol/Nomex uniform was at least 67% higher than that measured for the HW Kynol/Nomex and cotton uniforms. Analysis of the burn area curves for 0% body burn show that no burns would have been sustained with the LW Kynol/Nomex uniform at a total heat of 5.0 g cal/cm^2 and approximately 5.5 to 5.7 g cal/cm^2 for the HW Kynol/Nomex and cotton uniforms.

FIGURE 9.
PERCENT BODY BURN VS TOTAL HEAT (CAL./SQ. CM)
CLOSE PROXIMITY



DISCUSSION

Heat Resistance (Table XXVIII)

In terms of heat resistance (vertical flammability and char through time), the HW and LW Kynol/Nomex uniform fabrics were similar to the cotton uniform fabrics for vertical flammability resistance but significantly better with respect to char through. Averaging the results obtained for the fabrics used in each uniform type for the 1.0 g cal/cm^2/sec radiant heat flux level, the LW and HW Kynol/Nomex uniform fabrics were 3.4 to 3.2 to 1, respectively, better than the cotton uniform fabrics in terms of char through time. As indicated previously the fact that burn injury occurs with the Kynol/Nomex fabrics long before char through occurs with the cotton fabrics negates to some degree the higher heat resistance benefit associated with the Kynol/Nomex fabrics.

Time to Burn Injury

Radiant Heat (Table XXVIII)

In the radiant heat tests at a heat flux level of 0.5 g cal/cm^2/sec using the average results obtained for the fabrics used in each uniform type, the cotton uniform fabrics provided 22% more protection time for the non contact case and 50% more protection time in the contact case compared to the HW Kynol/Nomex uniform fabrics. Compared to the LW Kynol/Nomex uniform fabrics the cotton uniform fabrics provided at least 50% more protection time for either the non-contact or contact case.

Flame Impingement (Table XXVIII)

Again, using the average results obtained for the fabrics used in each uniform type at a flame impingement exposure of 2.0 g cal/cm^2/sec the cotton uniform fabrics showed superior protection times than the LW and HW Kynol/ Nomex uniform fabrics. Protection time was 43% longer with the cotton uniform fabrics versus the HW Kynol/Nomex uniform fabrics and 100% longer when the cotton uniform fabrics were compared to the LW Kynol/Nomex uniform fabrics.

Total Heat Protection

Flame Envelopment (Table XXVIII)

For new garments at the 0% body burn level, the HW Kynol/Nomex uniform had a total heat protection factor of 1.6 to 1 compared to the LW Kynol/Nomex uniform and 1.1 to 1 compared to the cotton uniform. The cotton uniform had a total heat protection factor of 1.4 to 1 compared to the LW Kynol/Nomex uniform. At a total heat of 10.0 g cal/cm^2/sec the HW Kynol/Nomex uniform had a percent body area burn protection factor of 2.0 to 1 with respect to the LW Kynol/Nomex uniform and a 1.1 to 1 protection factor with respect to the cotton uniform. The cotton uniform percent body area burn protection factor was 1.8 to 1 compared to the lightweight Kynol/Nomex uniform. Because of the variability in these test results, the differences in protection measured between the HW Kynol/Nomex uniform and the cotton uniform were not considered significant. The protection differences between the HW Kynol/Nomex and cotton uniforms compared to the LW Kynol/Nomex uniform were significant.

Close Proximity Exposures to Fires (Table XXVIII)

For new garments the HW Kynol/Nomex and cotton uniforms showed equivalent protection at the 0% body burn level and both had a total heat protection factor of 1.1 to 1 compared to the LW Kynol/Nomex uniform. At a total heat of 10 gcal/cm^2 the cotton uniform showed superior protection to both Kynol/Nomex uniforms. The percent body area burn protection factor for the cotton uniform at this total heat level was 1.4 to 1 compared to the HW Kynol/Nomex uniform and 2.3 to 1 compared to the LW Kynol/Nomex uniform. The differences in total heat protection factors at the 0% body burn level were not considered significant between the cotton and both Kynol/Nomex uniforms, but the percent body area burn protection factors for the cotton uniform at the 10 g cal/cm^2 in comparison to both Kynol/Nomex uniforms were considered significant.

TABLE XXVIII RELATIVE HEAT PROTECTION CHARACTERISTICS OF NEW KYNOL/NOMEX AND FRT COTTON UNIFORMS

Characteristic	Time of Exposure	Heat Flux (g cal/cm^2/sec)	LW Kynol/Nomex	HW Kynol/Nomex	FRT Cotton
Vertical Flammability Resistance	Flame 12 sec	--	1	1	1
Char Through Resistance (Avg)	Radiant	1.0	3.4	3.2	1
Time to Burn Injury (Avg)	Radiant	0.5			
	a. 0.5 in. away		1	1.3	1.5
	b. Contact		1	1.2	1.8
	Flame Impingement (contact)	2.0	1	1.4	2.0
Total Heat Protection					
0% Burn	Flame Envelopment	--	1	1.6	1.4
% Body Burn Area		10.0 gcal/cm^2	1	2.0	1.8
0% Burn	Close Proximity	--	1	1.1	1.1
% Body Burn Area		10.0 gcal/cm^2	1	1.7	2.3

CONCLUSIONS

1. Vertical flammability resistance of the three Kynol/Nomex fabrics and the two FRT cotton fabrics evaluated was excellent initially and after 15 simulated shipboard launderings using Navy shipboard wash formula II. No after flame occurred with any of the samples and the maximum average char length for any 12 inch sample was 3.5 inches.

2. In char through tests none of the Kynol/Nomex and cotton fabrics ignited in the radiant heat exposures (0.3 to 1.0 g cal/cm^2/sec). At the highest heat flux level used in these tests (1.0 g cal/cm^2/sec) both cotton fabrics (6.5 oz/yd^2 chambray and 12.0 oz/yd^2 denim) showed significantly lower heat resistance than the three Kynol/Nomex fabrics evaluated (4.5 oz/yd^2, 70/30% blend; 6.0 oz/yd^2, 70/30% blend; and 8.0 oz/yd^2, 80/20% blend). Char through times were 10 and 11 seconds for the cotton fabrics and 34, 38, and 29 seconds for the Kynol/Nomex fabrics. The two 70/30% blend Kynol/Nomex fabrics (4.5 oz/yd^2 and 6.0 oz/yd^2) which had the greater percentage of Nomex showed more resistance to char through (at least 5 seconds greater char through time) than the 8.0 oz/yd^2, 80/20% blend Kynol/Nomex fabric. At char through all of the fabrics disintegrated when touched.

3. In radiant heat protection tests with the fabrics in contact with the heat sensor or one-half inch away from the heat sensor, the TBI was related primarily to fabric weight. In most cases for all heat flux levels evaluated the heavier fabric provided the longest protection time regardless of what fiber the fabric was made from. The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton materials. Weight of the fabrics was more a measure of potential burn protection than any other material property.

4. In comparing char through time and TBI data for the radiant exposure tests it was noted that the TBI for any of the heat flux levels evaluated would have occurred with any of the Kynol/Nomex fabrics long before char through would have happened with the cotton fabrics. Thus the benefit of using the higher heat resistant Kynol/Nomex fabrics is somewhat negated since burn injury is sustained with the Kynol/Nomex fabrics long before char through occurs with the cotton fabrics.

5. As with the radiant heat exposure tests, burn protection time in the flame impingement tests was directly related to the weight of the test fabrics and not the particular fibers the fabrics were made from. The heavier the fabric the greater the heat protection time. The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton fabrics.

6. In the two second flame envelopment tests the HW Kynol/Nomex uniform ($6.0\ oz/yd^2$ shirt and $8.0\ oz/yd^2$ trouser), and the cotton uniform ($6.5\ oz/yd^2$ shirt and $12.0\ oz/yd^2$ trouser) showed similar protection characteristics. The average total body area burn was 5% at an average total heat of $5.4\ g\ cal/cm^2$ for the cotton uniform versus 4% average total body area burn at an average total heat of $5.0\ g\ cal/cm^2$ for the HW Kynol/Nomex uniform. The protection provided by the LW Kynol/Nomex uniform ($4.5\ oz/yd^2$ shirt and $6.0\ oz/yd^2$ trouser) was at least 44% less than the protection provided by the other two uniform types. The average total body area burn for this uniform was 9% at an average total heat level of $4.8\ g\ cal/cm^2$. Based on the average results the relative differences between the uniforms regarding protection after fifteen simulated shipboard launderings were similar to those measured for the new uniforms (Table XXI).

7. In tests of uniforms in close proximity to fuel fires (10 and 20 feet) for 100 seconds the cotton uniforms showed greater protection than either the HW or LW Kynol/Nomex uniforms with the HW Kynol/Nomex uniform being more protective than the LW Kynol/Nomex uniform (Fig. 9).

8. The Kynol/Nomex fabrics/uniforms did not show superior protection/heat resistant characteristics to the cotton fabrics/uniforms in any of the heat protection tests or the vertical flammability tests. Only in the char through tests did the higher thermal resistance of the Kynol/Nomex materials show significant benefit versus the cotton materials. However, body burns would have been sustained with the Kynol/Nomex materials long before char through would have occurred with the cotton materials.

For further details see Tab D.

DYEING AND FINISHING STUDY

INTRODUCTION

The commercial survey conducted indicated that all Kynol and Kynol blended fabrics marketed in the United States today were sold in their natural gold color. Additionally, information developed in the survey indicated that the fiber was difficult to dye and that any color previously utilized had poor colorfastness properties to light because of the darkening of the Kynol fiber when exposed to ultraviolet radiation. Promotional literature from American Kynol Incorporated indicated that Kynol fabrics could be dyed dark colors without any adverse results.

To establish the dyeing and performance characteristics of dyed Kynol fabrics, a research and development contract was awarded to Albany International Research Co., an organization with expertise in the dyeing and finishing of FR materials. The objectives of the work were to select suitable dyeing and finishing chemicals for imparting a dark blue color similar to Navy Shade Blue 3375 and develop procedures for affixing the chemicals to three Kynol/Nomex blended materials which would produce good colorfastness properties while maintaining suitable fabric physical and flame resistance properties.

The fabrics dyed were 4.9 oz/yd^2, 70/30% Kynol/Nomex, (Code A); 6.5 oz/yd^2, 70/30% Kynol/Nomex, (Code B); and 8.4 oz/yd^2, 80/20% Kynol/Nomex (Code C). The fabric weights were based on undyed-desized materials.

Additionally, the contract included the evaluation of finishes which would improve the abrasion resistance properties of the Kynol fabrics. Abrasion tests conducted on these fabrics (Tab A) indicated that improvement in this property was needed to insure adequate long term wear potential.

The development effort was accomplished in three phases involving laboratory work, Phase I: pilot plant work; Phase II; and production work; Phase III.

PHASE I LABORATORY WORK

Initially in this phase the physical and flame resistant properties of the undyed and desized fabrics were established utilizing appropriate tests contained in the Federal Standard for Textile Test Methods No. 191. The properties tested included weight, construction, break and tear strength, air permeability, abrasion resistance, and vertical flammability resistance for each fabric.

The dyeing properties of the Kynol/Nomex fabrics were evaluated and a number of dyes were selected along with chemical assistants needed to produce suitable dyeings. Laboratory dyeing trials were performed to establish the classes of dyes best suited to meeting the desired Navy Blue 3375 shade.

The undyed fabric as utilized in the shipboard evaluation had a permanent press finish. The application of this finish along with an antistatic finish and other finishes to improve fabric properties such as abrasion resistance were also evaluated.

Undyed Fabric Properties

Prior to testing the undyed fabrics to develop their physical properties, the fabrics were tested to determine the presence of sizing. These tests were positive and indicated the presence of polyvinyl alcohol, a product used to improve fabric processing. The sizing was removed by treatment with caustic soda, followed by rinsing and scouring with an anionic surfactant (Witconate 60L). It was found that the desizing process caused the fabrics to shrink 5.5% in the warp and up to 2.0% in the filling.

The properties of the undyed-desized fabrics are given in Table XXIX. The fabric weights were 4.9 oz/yd^2 for the 70/30% Kynol/Nomex blend (Code A), 6.5 oz/yd^2 for the 70/30% Kynol/Nomex blend (Code B), and 8.4 oz/yd^2 for the 80/20% Kynol/Nomex blend (Code C). The tear and break strength of fabrics appeared adequate. Abrasion resistance for all three fabrics was low considering long term wear potential. The vertical flammability resistance of the fabrics was considered good. These results differed from in-house results, particularly with respect to abrasion resistance. Albany used a harsher abradant in their tests so their abrasion results cannot be compared directly to those shown in Tables III and IV, but showed for the most part the same relative differences between the fabrics.

Dyeing Trials

A number of cationic and dispersed dyes were evaluated to determine if the desired blue shade could be obtained. The dyes were applied with benzyl alcohol as the dyeing assistant. Since available literature indicated that Kynol fibers can be dyed with either cationic or dispersed dyes and Nomex fibers can be dyed with cationic dyes, two dyeing approaches were considered: (1) dyeing both the Kynol and Nomex fibers with cationic dyes, and (2) dyeing the Kynol and Nomex fibers with a combination of dispersed and cationic dyes. Method (1) did not achieve the desired shade while method (2) did yield a shade approximating the desired color. Table XXX illustrates the dye formulation and procedure used (Method (2)) for the coloration of the three Kynol/Nomex fabrics.

Finishing

Different finishing methods were evaluated which included durable press, antistat, and abrasion resistant finishes. Results indicated that the antistat finishes reduced vertical flammability resistance by causing unacceptable glow times at the end of the flame exposures and as a result they were eliminated from further consideration. Ultimately the finish formulation selected contained only an abrasion resistant finish (Butvar Dispersion BR resin, Monsanto; A.I. Finish #2).

Results

The colorfastness and flammability resistance properties with the AI finish #2 are shown in Table XXXI. As can be seen, colorfastness to laundering, perspiration, and crocking were acceptable as well as vertical flammability resistance. However, colorfastness to light and color staining of the Nylon fiber in the multifiber control swatch was poor.

These results represented a best effort for the time constraints imposed by the program and Phases II and III were conducted using this dyeing and finishing formulation.

PHASE II. PILOT PLANT DYEING AND FINISHING

The dyeing and finishing work was performed at Native Textiles located in Glen Falls, NY. The plant trial work was based on the formulation developed in Phase I (Table XXX). However, the amount of chemicals and dyeing and scouring temperatures used and other process variables were changed to achieve even dyeings under these quasi-production conditions (Table XXXII).

Results

Fabrics A and B were joined in an endless rope and dyed in a Gaston County 80 pound capacity jet dyeing machine while Fabric C was dyed in a 5.75 pound capacity jet dyeing machine. The dyed and finished fabrics were evaluated to determine any change in physical, colorfastness and flammabilitty properties as shown in Tables XXXIII and XXXIV.

As can be seen in Table XXXIII, the physical properties of the dyed and finished fabrics were in general better than the undyed fabrics. This was in part due to weight changes from the undyed fabrics (5.4 vs. 4.9 oz/yd^2, 7.4 vs. 6.5 oz/yd^2, and 9.7 vs. 8.4 oz/yd^2). Increases were noted in breaking strength and in tear strength except for fabric C in the filling direction, and there were significant improvements in abrasion resistance for all fabrics. There were slight increases in air permeability for fabrics A and B but this property decreased 50% for fabric C. Colorfastness (Table XXXIV) was similar to the lab scale results for laundering, perspiration and light, but there were some negative changes related to dry and wet crocking and staining of the multifiber control swatch for all of the fabrics. Flammability resistance was still considered good for all fabrics.

PHASE III PRODUCTION DYEING AND FINISHING

The production dyeing and finishing was also performed at Native Textiles in Glen Falls, NY. Based on additional laboratory experimentation it was determined that a longer dyeing time at higher temperatures could produce a higher dye exhaustion resulting in a reduction in the amount of dye used, except for fabric C. Table XXXV reflects the amounts of dyestuffs used. The procedure used was identical to that used in Phase II except that the dyeings were done at a higher temperature (275°F vs. 265°F) and for a longer period (90 min. vs. 60 min.). Fabrics A and B (432 yards total) were dyed simultaneously in a Gaston County jet dyeing machine while fabric C (220 yards) was dyed separately in the same type of equipment.

Results

The physical and colorfastness and flammability properties of the fabrics are shown in Table XXXVI and XXXVII. As can be seen in Table XXXVI, the fabric weights for fabrics A and B were similar to the Phase II fabrics but fabric C was noticeably heavier (11.3 vs. 9.7 oz/yd^2) than its Phase II counterpart (Table XXXIII). Breaking strengths were for the most part lower than the Phase II fabrics but still acceptable and improved from the undyed fabrics. Tear strength improvements indicated in Phase II were not only lower for the most part in Phase III but below those measured for the undyed fabrics in Phase I for fabrics A and C. Air permeabilities were similar to Phase II. Abrasion resistance was similar to Phase II for fabric B, and substantially better than Phase II for fabric C, but somewhat lower than Phase II for fabric A. Abrasion resistance for all fabrics was still superior to their undyed counterparts.

Colorfastness properties (Table XXXVII) compared to Phase II (Table XXXIV) were similar for laundering and light. Compared to Phase II there were improvements in colorfastness to perspiration and crocking for all fabrics and some improvement in staining of the multifiber control swatch for fabrics A and B, but some reduction in this characteristic for fabric C. Flammability resistance was still considered good for all fabrics.

CONCLUSION

The laboratory work conducted in Phase I showed that Kynol/Nomex fabrics could be dyed a color similar to the Navy Blue 3375 shade. Satisfactory shade colorfastness properties were obtained for laundering, resistance to perspiration, and crocking. However, in laundering there was significant staining of the nylon component of the multifiber control swatch. Colorfastness to light was also poor. The addition of a topical finish increased abrasion resistance significantly for all fabrics over their undyed-desized counterparts, but the weights of the fabrics were also increased significantly because of the additon of this finish. The use of an antistat finish was found to reduce the flammability resistance and was omitted in the final formulation. The pilot plant work in Phase II and the production dyeing in Phase III for the most part produced similar results as the lab trials.

The major problem resulting from dyeing these fabrics was poor lightfastness which related more to the influence of ultraviolet light on the Kynol fiber rather than the dyestuffs. The Kynol fiber became darker in shade when exposed to light, causing a darkening of the shade of the fabric. Whether this can be prevented by using an ultraviolet inhibiter was not determined in this study. The flammability resistance of any of the fabrics was not adversely effected with the dyeing and finishing chemicals finally chosen.

The cost for dyeing and finishing these fabrics is estimated at $2.43 for Fabric A, $3.21 for Fabric B, and $4.45 for Fabric C.

For further information see Tab E.

TABLE XXIX UNDYED FABRIC CHARACTERISTICS

Property	Test Method	Sample A		Sample B		Sample C	
Weight (oz/yd^2)	5041	4.9		6.5		8.4	
Weave	Visual	plain		plain		1/2 twill	
		Warp	Filling	Warp	Filling	Warp	Filling
Tensile Strength (lbs)	5100	95	82	131	94	145	120
Tear Strength (lbs)	5132	6.4	5.9	6.4	3.7	8.1	6.2
Threads per Inch	5050	52	46	80	46	78	50
Air Permeability ($cu\ ft/min/ft^2$)	5450	94		17		28	
pH	2811	6.6	6.7	7.0	7.0	7.1	7.0
Nonfibrous Content	2611	3.9		3.4		3.1	
Flammability* (char length in.)	5903	2.5	2.9	2.3	2.2	2.0	1.8
Yarn ply	visual	2 ply (w & f)		2 ply (w & f)		2 ply (w & f)	
Abrasion (cycles)	5302	30		90		270	

* The specimens did not exhibit an after glow or after flame

TABLE XXX DYE FORMULATION AND PROCEDURE USED FOR THE COLORATION OF KYNOL/NOMEX BLENDED FABRICS (LABORATORY WORK)

All dyeings were based on a 40:1 water/fabric weight ratio (see below). All dyeings were performed using 20 grams/liter benzyl alcohol, 5 grams/liter Witconate 60L (based on 100% activity) and 5% formic acid (85%) based on the weight of fabric.

Fabric Identification	Name of Dye	Manufacturer	Generic Name	Color Index No.	Amount Used (%)*
A	Celliton Fast Red Violet RNA**	GAF	Disperse Violet I	61100	4.5
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
B	Celliton Fast Red Violet RNA	GAF	Disperse Violet I	61100	4.5
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
C	Celliton Fast Red Violet RNA	GAF	Disperse Violet I	61100	5.3
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	2.5

* Based on the weight of fabric

** Also available from Atlantic Industries and Crompton Knowles Corp.

Procedure: The required amount of benzyl alcohol was combined with Witconate 60L and then added to water to obtain a dispersion of the benzyl alcohol. This dispersion was then added to the wet-out fabric. After approximately 5 minutes of agitation, formic acid was added followed by the required amount of dissolved and diluted dyes. The fabric was agitated in the dyebath for approximately 5 minutes at room temperature. The stainless steel container was then closed and loaded into a Launderometer containing ethylene glycol as the heating medium. The rate of rise was set at 5.5°F/min. After reaching 265°F the bath temperature was maintained for 60 minutes.

Following the cool down cycle the fabric was rinsed with hot water and then scoured.

Scouring of Dyed Fabric: The fabric was scoured for 20 minutes at 180°F with 1 gram/liter trisodium phosphate and 1.5 grams/liter Witconate 60L (based on 100% activity), then rinsed with warm water. This procedure was repeated twice. The scoured fabric was then passed between squeeze rolls to remove excess water, and then dried for 5 minutes at 300°F.

Table XXXI Colorfastness and Flammability Properties of Finished Fabrics
(Laboratory Work)

Fabric Identification AI Finish #2	Laundering, TM 5610 Color Change Pass or Fail	Laundering, TM 5610 Staining Pass or Fail	Perspiration, Test Method 5680 Alkaline Color Change	Alkaline Staining	Acid Color Change	Acid Staining	SFH Light, TM 5660	Crocking, TM 5651 Wet	Crocking, TM 5651 Dry	pH, TM 2811	Flammability, Test Method 5903 Char Length (inches) Warp	Char Length (inches) Fill	After Glow (seconds) Warp	After Glow (seconds) Fill	After Flame (seconds) Warp	After Flame (seconds) Fill
Fabric A	Pass	Fail	Good		Good		Fail 20	Good	Good	6.5	2.4	2.4	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric B	Pass	Fail	Good		Good		Fail 20	Good	Good	6.9	2.4	2.1	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric C	Pass	Fail	Good		Good		Fail 20	Fair	Good	7.0	1.6	1.4	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Calibration L-4 Wool Standard																

SFH = Standard Fading Hours

Key: *A=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.

TABLE XXXII DYE FORMULATION AND PROCEDURE USED FOR THE COLORATION OF KYNOL/NOMEX BLENDED FABRICS (PHASE II)

All dyeings were performed using 60 grams/liter benzyl alcohol, 5 grams/liter Witconate 60L (based on 100% activity) and 5% formic acid (85%) based on the weight of fabric.

Fabric Identification	Name of Dye	Manufacturer	Generic Name	Color Index No.	Amount Used (%)*
A	Celliton Fast Red Violet RNA**	GAF	Disperse Violet I	61100	7.25
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
B	Celliton Fast Red Violet RNA	GAF	Disperse Violet I	61100	7.25
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
C	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	7.6
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	2.5

* Based on the weight of fabric

** Also available from Atlantic Industries and Crompton Knowles Corp.

Procedure: The required amount of benzyl alcohol was combined with Witconate 60L and then added to the wet-out fabric in the machine. After 5 minutes, formic acid was added followed by the required amount of dissolved and diluted dyes. Following another holding period of 5 minutes the temperature was raised in accordance with the established program profile (Tab E).

Scouring Procedure: The fabric was scoured for 30 minutes at 180°F with 1 gram/liter trisodium phosphate, 1.0 grams/liter Witconate 60L (based on 100% activity), and 1.0 gram/liter sodium hydrosulfite. The fabric was finally given two rinses with warm water before removal from the jet machines.

Finishing Procedure: The dyed scoured fabrics were passed into a trough overflowing with warm water to permit complete wetting and also to provide an additional rinse. The fabrics next allowed to pass between squeeze rolls to remove excess water and to provide a uniform water content (approximately 70% wet pick up) prior to drying. The drying was performed on an Artos pin frame set at 250°F, and a running speed of 8 yds/min. After drying the fabric was passed through a diluted Butvar dispersion sufficient to yield a 1% dry add-on of the product. The temperature of drying/curing was increased to 300°F and the speed of the Artos pin frame to 10 yds/min during the application of the finish.

TABLE XXXIII FABRIC CHARACTERISTICS (Phase II)

Property	Test Method	Condition	Sample A		Sample B		Sample C*	
Weight (oz/yd²)	5041		5.4		7.4		9.7	
			Warp	Filling	Warp	Filling	Warp	Filling
Breaking Strength (lbs)	5100	Undyed	95	82	131	94	145	120
		Dyed	120	94	185	97	190	132
Tear Strength (lbs)	5132	Undyed	6.4	5.9	6.4	3.7	8.1	6.2
		Dyed	7.7	7.0	7.9	4.6	7.9	5.2
Threads/Inch	5050	Undyed	52	46	80	46	78	50
		Dyed	56	48	82	49	84	53
Air Permeability (cu ft/min/ft²)	5450	Undyed	94		17		28	
		Dyed	96		23		14	
Abrasion (cycles)	5302	Undyed	30		90		270	
		Dyed	125		318		628	

* This fabric was processed in the small laboratory jet dyeing machine, whereas Fabrics A and B were processed together in a larger laboratory machine.

Table XXXIV Colorfastness and Flammability Properties of Finished Fabrics (Phase II)

Fabric Identification BR Dispersion Finish	Laundering, TM 5610 Color Change Pass or Fail	Laundering, TM 5610 Staining Pass or Fail	Perspiration, Test Method 5680 Alkaline Color Change	Alkaline Staining	Acid Color Change	Acid Staining	SFH Light TM 5660	Crocking TM 5651 Wet	Crocking Dry	pH, TM 2811	Flammability, Test Method 5903 Char Length (inches)** Warp	Char Length Fill	After Glow (seconds) Warp	After Glow Fill	After Flame (seconds) Warp	After Flame Fill
Fabric A	Pass	Fail	Good		Good		Fail 20	Fair	Fair	6.7	1.9	2.2	0	0	0	0
		A* Poor														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric B	Pass	Fail	Good		Good		Fail 20	Good	Fair	6.2	2.0	1.5	0	0	0	0
		A* Poor														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric C	Pass	Fail	Good		Good		Fail 20	Good	Fair	5.6	2.3	2.1	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														

Lamp calibration (SFH)
L-4
Wool standard

Key: *=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.

**Values for the undyed fabrics

	Char Length (in.) Warp	Fill
A	2.5	2.9
B	2.3	2.2
C	2.0	1.8

no after glow or after flame

TABLE XXXV DYE FORMULATION AND PROCEDURE USED FOR THE COLORATION OF KYNOL/NOMEX BLENDED FABRICS (PHASE III)

Fabric Identification	Name of Dye	Manufacturer	Generic Name	Color Index No.	Amount Used (%)
A	Celliton Fast Red Violet RNA**	GAF	Disperse Violet I	61100	6.48
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	3.89
B	Celliton Fast Red Violet RNA	GAF	Disperse Violet I	61100	6.48
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	3.89
C	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	12.19
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	3.20

TABLE XXXVI FABRIC CHARACTERISTICS (Phase III)

Property	Test Method	Condition	Sample A		Sample B		Sample C	
Weight (oz/yd^2)	5041		5.6		7.5		11.3	
			Warp	Filling	Warp	Filling	Warp	Filling
Breaking Strength (lbs)	5100	Undyed	95	82	131	94	145	120
		Dyed	106	79	174	104	198	132
Tear Strength (lbs)	5132	Undyed	6.4	5.9	6.4	3.7	8.1	6.2
		Dyed	5.1	4.0	7.3	3.5	6.8	4.0
Threads/Inch	5050	Undyed	52	46	80	46	78	50
		Dyed	55	49	81	44	82	51
Air Permeability ($cu\ ft/min/ft^2$)	5450	Undyed	94		17		28	
		Dyed	89		20		15	
Abrasion (cycles)	5302	Undyed	30		90		270	
		Dyed	89		331		935	

Table XXXVII Colorfastness and Flammability Properties of Finished Fabrics (Phase III)

Fabric Identification BR Dispersion Finish	Laundering, TM 5610 Color Change Pass or Fail	Laundering, TM 5610 Staining Pass or Fail	Perspiration, Test Method 5680 Alkaline Color Change Staining	Perspiration, Test Method 5680 Acid Color Change Staining	SFH Light TM 5660	Crocking TM 5651 Wet	Crocking TM 5651 Dry	pH, TM 2811	Flammability, Test Method 5903 Char Length (inches)** Warp	Char Length (inches)** Fill	After Glow (seconds) Warp	After Glow (seconds) Fill	After Flame (seconds) Warp	After Flame (seconds) Fill
Fabric A	Pass	Fail	Excellent	Excellent	Fail 20	Good	Good	7.7	2.7	2.8	0	0	0	0
		A* Good												
		C Excellent												
		N Poor												
		P Excellent												
		A Excellent												
		W Excellent												
Fabric B	Pass	Fail	Excellent	Excellent	Fail 20	Good	Good	6.5	3.1	2.7	0	0	0	0
		A* Fair												
		C Excellent												
		N Poor												
		P Excellent												
		A Excellent												
		W Excellent												
Fabric C	Pass	Fail	Excellent	Excellent	Fail 20	Good	Good	6.2	2.3	2.1	0	0	0	0
		A* Poor												
		C Excellent												
		N Poor												
		P Excellent												
		A Excellent												
		W Excellent												

Lamp calibration
L-4
Wool standard

SFH = Standard Fading Hours

Key: *=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.
**Values for the undyed fabrics

	Char Length (in.) Warp	Char Length (in.) Fill
A	2.5	2.9
B	2.3	2.2
C	2.0	1.8

no after glow or after flame

POTENTIAL COST OF KYNOL/NOMEX UNIFORMS

Table XXXVIII shows the cost breakdown for the LW and HW Kynol/Nomex uniforms using undyed and dyed fabrics and the cost of the cotton uniform dyed. Cost data show that the LW Kynol/Nomex uniform would be at least 2.3 times more expensive than the cotton uniform and the HW Kynol/Nomex uniform would be at least 2.8 times more expensive than the cotton uniform.

TABLE XXXVIII COST OF KYNOL/NOMEX AND FRT COTTON UNIFORMS

Uniform	Fabric Cost ($/yd^2) Undyed	Fabric Cost ($/yd^2) Dyed	Fabric Utilization Cost ($) Undyed	Fabric Utilization Cost ($) Dyed	Man'f Cost ($)	Total Cost ($) Undyed	Total Cost ($) Dyed
LW Kynol/Nomex							
Shirt	12.25	14.68	24.50	29.36	7.00	31.50	36.36
Trouser	15.00	18.21	30.00	36.42	6.00	36.00	42.42
Total						67.50	78.78
HW Kynol/Nomex							
Shirt	15.00	18.21	30.00	36.42	7.00	37.00	43.42
Trouser	18.60	23.05	37.20	46.10	6.00	43.20	52.10
Total						80.20	95.52
FRT Cotton							
Shirt	--	3.50	--	7.00	7.00	--	14.00
Trouser	--	4.50	--	9.00	6.00	--	15.00
Total						--	29.00

GENERAL DISCUSSION

MATERIALS INVESTIGATION

Physical Properties (Tables III and IV)

The break and tear strength characteristics of the Kynol/Nomex and cotton fabrics evaluated in this study indicated that these fabrics were suitable for use in utility shirts and trousers. The major difference noted between the Kynol/Nomex and cotton fabrics was their resistance to abrasion. The cotton shirt fabric had an abrasion resistance factor 4.3 times higher than the LW Kynol/Nomex uniform shirt fabric and 1.7 times higher than the HW Kynol/Nomex uniform shirt fabric. The cotton trouser fabric had an abrasion resistance factor 7.0 times higher than the LW Kynol/Nomex uniform trouser fabric and 2.9 times higher than the HW Kynol/Nomex uniform trouser fabric. This abrasion resistance data suggest that the cotton uniform would have a longer potential use life than the Kynol/Nomex uniforms, especially when compared to the LW Kynol/Nomex uniform.

Launderability (Table V)

Both the Kynol/Nomex and cotton fabric uniforms showed progressive shrinkage characteristics in multiple laundering tests. After fifteen launderings the cotton shirt showed less shrinkage than the LW and HW Kynol/Nomex shirts by a factor of at least 1.7 to 1. For the trousers after fifteen launderings, the shrinkage characteristics for the HW Kynol/Nomex and cotton fabrics were similar while the LW Kynol/Nomex fabric showed less shrinkage than the cotton fabric by a factor of 1.4 to 1.

After multiple launderings the hand of the Kynol/Nomex fabrics was more negatively effected than the cotton fabrics. The Kynol/Nomex fabrics were very limp, indicating some loss of the durable press finish which had been applied to the fabrics.

SHIPBOARD EVALUATION

Functional Properties (Table X)

Information developed in this evaluation indicated that both the Kynol/Nomex and cotton uniforms were rated similarly for appearance after laundering, durability, and heat protection. Some differences were noted in fit after laundering and comfort. The fit of the cotton uniform was indicated to be at least 10% better than the HW Kynol/Nomex uniform, while there were no differences noted in this property between the HW and LW Kynol/Nomex uniforms. Comfort was perceived to be the same for the cotton and HW Kynol/Nomex shirts while the LW Kynol/Nomex shirt was noted to be 20% more comfortable than the HW Kynol/Nomex shirt. The cotton trouser was perceived to be 30% more comfortable than the HW Kynol/Nomex trouser and the LW Kynol/Nomex trouser was noted to be 10% more comfortable than the HW Kynol/Nomex trouser. Relative differences noted between these three uniforms indicated that the cotton uniform was slightly better than either Kynol/Nomex uniform for fit after laundering, while the LW Kynol/Nomex shirt provided slightly better comfort than the HW Kynol/Nomex and cotton shirts, and the cotton trouser provided slightly better comfort than either the LW or HW Kynol/Nomex trousers.

Preference (Table X)

The cotton uniform was the most preferred uniform. In direct comparisons the cotton uniform was preferred by a factor of 3.2 to 1 over the HW Kynol/Nomex uniform, and the LW Kynol/Nomex uniform was preferred by a factor of 1.3 to 1 over the HW Kynol/Nomex uniform. Relative comparisons between these three uniforms indicates that the cotton uniform was preferred by at least 3.2 to 1 over either the LW or HW Kynol/Nomex uniform.

PHYSIOLOGICAL EVALUATION

There were no significant differences in heat stress indicators (tolerance times and changes in rectal temperature, skin temperature, and heart rate) between the cotton and LW and HW Kynol/Nomex uniforms for a moderate work activity under the three environmental conditions employed (70°F, 50% RH; 95°F, 70% RH; and 120°F, 20% RH). Subjective comfort ratings by the test volunteers indicated the cotton uniform was more comfortable than either Kynol/Nomex uniform. The HW Kynol/Nomex uniform was disliked by all test volunteers.

HEAT PROTECTION

Heat Resistance (Tables XVI and XXVIII)

The vertical flammability resistance for the cotton and Kynol/Nomex fabrics was excellent when new and after fifteen simulated shipboard launderings. The resistance to char through measured as char through time in radiant heat exposures was superior for the Kynol/Nomex fabrics over the cotton fabrics. At a radiant heat flux of 1.0 g $cal/cm^2/sec$ the Kynol/Nomex fabrics were more resistant to this property by a factor of at least 3.2 to 1 over the cotton fabrics. However, in subsequent radiant heat tests to establish burn time protection provided by these fabrics it was noted that burn injury would have been sustained with the Kynol/Nomex fabrics long before char through would have occurred with the cotton fabrics for equivalent flux levels, indicating that the higher heat resistance of the Kynol/Nomex fabrics, although desirable, does not provide any benefit with respect to burn protection. Burn protection either expressed as TBI or in percent body area burned in heat protection tests was determined to be primarily related to the weight of the fabric/uniform than the fiber composition of the fabric/uniform.

Heat Protection

Time to Burn Injury (Table XXVIII)

In radiant and flame impingement exposures of the cotton and Kynol/Nomex fabrics at various heat flux levels all data indicated that the times estimated before burn injury would occur were directly related to the weights of the fabrics (greater weight-longer burn protection times) and not to their fiber composition. In no instance did the Kynol/Nomex fabrics show any unique ability to extend the time before burn injury would occur with respect to the cotton fabrics. In averaging the results obtained with the various uniform fabrics (cotton chambray shirt and denim trouser, and LW and HW Kynol/Nomex shirt and trouser components) the cotton uniform was more protective than the HW Kynol/Nomex uniform by at least a factor of 1.2 to 1 and as much as 1.5 to 1, and with respect to the LW Kynol/Nomex uniform the cotton uniform was more protective by at least a factor of 1.5 to 1 and as much as 2.0 to 1 in the radiant and flame impingement fabric exposures.

Total Heat Protection (Figs. 7 and 9)

In flame envelopment and close proximity fire protection tests of the cotton and LW and HW Kynol/Nomex uniforms, the results as in the TBI tests indicated that the degree of protection achieved was again related primarily to the weights of the uniforms and not to their fiber composition.

The total heat required before a burn would have been sustained for new cotton and HW Kynol/Nomex uniforms was similar in the close proximity fire tests and 14% higher for the HW Kynol/Nomex uniform than the cotton uniform in the flame envelopment tests. The total heat required before a burn would have been sustained with the cotton and HW Kynol/Nomex uniforms compared to the LW Kynol/Nomex uniform was 10% higher for the close proximity fire tests and at least 38% higher in the flame envelopment tests.

The percent body area which sustained burns at a total heat of 10 g cal/cm^2 was 26% lower for the cotton uniform compared to the HW Kynol/Nomex uniform and 56% lower for the cotton uniform compared to the LW Kynol/Nomex uniform in the close proximity fire tests. In the flame envelopment tests the percent body area which sustained burns at a total heat of 10 g cal/cm^2 was 7% higher for the cotton uniform compared to the HW Kynol/Nomex uniform and 51% lower for the cotton uniform compared to the LW Kynol/Nomex uniform.

DYEING AND FINISHING STUDY

Some degree of success was achieved in dyeing the Kynol/Nomex fabrics to an acceptable blue shade. However, the colorfastness properties of the dyed fabrics to light and staining of the nylon fiber component of the multifiber control cloth was poor. Poor lightfastness was not fully attributed to the dyestuffs used but relates more to the darkening of the Kynol fiber when exposed to ultraviolet radiation which causes the fabric to become darker in shade. Vertical flammability resistance of the fabrics was not effected by the dyes and finishes finally employed.

Attempts were also made in this study to improve the abrasion resistance of the Kynol/Nomex fabrics by applying a finish to the fabrics after they were dyed. This finish provided a significant improvement in abrasion resistance over the undyed-desized fabrics. In order to compare the abrasion results achieved in this study with those measured for the Kynol/Nomex fabrics used in other aspects of this evaluation, since Albany used a harsher abradant than we did, the dyed fabrics received from the production dyeings were retested for this property with the same abradant used by us. The results were as follows:

a. 5.6 oz/yd^2, Kynol/Nomex, 70/30% blend -

   Abrasion Resistance - Albany 89 cycles, NCTRF 650 cycles

b. 7.5 oz/yd^2, Kynol/Nomex, 70/30% blend

   Abrasion Resistance - Albany 331 cycles; NCTRF 1450 cycles

c. 11.3 oz/yd^2, Kynol/Nomex, 70/20% blend

   Abrasion Resistance - Albany 935 cycles; NCTRF 2230 cycles

When compared to the undyed Kynol/Nomex fabrics with a durable press finish used in the other aspects of this evaluation, the change for the 4.5 oz/yd^2 fabric was 650 versus 280 cycles with a weight increase of 1.1 oz/yd^2 (5.6 oz/yd^2), 6.0 oz/yd^2 fabric was 1450 versus 710 cycles with a weight increase of 1.5 oz/yd^2 (7.5 oz/yd^2) and 8.0 oz/yd^2 fabric was 2230 versus 1700 cycles with a weight increase of 3.3 oz/yd^2 (11.3 oz/yd^2). Thus improvements in abrasion resistance were 1.3 to 2.3 times higher with a weight penalty 1.2 to 1.4 times higher for the Albany fabrics over the undyed durable press treated Kynol/Nomex fabrics. The best improvements when weight increases are considered were for the lighter two fabrics, where the weight increased by a factor of 1.2 to 1.3 and abrasion resistance increased by a factor of 2.0 to 2.3. Comparing the Albany fabrics with the abrasion resistant results for the 6.5 and 12.0 oz/yd^2 cotton fabrics, 1190 and 5000 cycles, respectively (Tables III and IV), it was noted for the shirting fabrics that the abrasion resistance for the 5.6 oz/yd^2 Kynol/Nomex fabrics is 1.8 times lower than the 6.5 oz/yd^2 cotton fabric, while the 7.5 oz/yd^2 Kynol/Nomex fabric has an abrasion resistance 1.2 times higher than the 6.5 oz/yd^2 cotton fabric. For the trouser fabrics, the abrasion resistance of the 12.0 oz/yd^2 cotton fabric is 3.4 times higher than the 7.5 oz/yd^2 Kynol/Nomex fabric and 2.2 times higher than the 11.3 oz/yd^2 Kynol/Nomex fabric. Based on these results, the two cotton fabrics would still appear to have longer wear potential than their shirting and trouser Kynol/Nomex fabric counterparts, except for the case of the 7.5 oz/yd^2 Kynol/Nomex shirting fabric which would potentially provide a wear life essentially equivalent to the 6.5 oz/yd^2 cotton shirting fabric, based on abrasion resistant test results.

The process of dyeing and adding an abrasion resistance finish substantially increased the weights of all the Kynol/Nomex fabrics. This was particularly true for the 8 oz/yd^2 fabric which weighed 11.3 oz/yd^2 after it was dyed and finished. This was caused in part by the shrinkage of the fabrics in processing as well as the weights of the dyeing and finishing chemicals used.

POTENTIAL COST OF KYNOL/NOMEX UNIFORMS

An analysis of the costs of the LW and HW Kynol/Nomex uniforms both undyed and dyed compared to the cotton uniforms established that the Kynol/Nomex uniforms would be at least 2.3 times more expensive than the cotton uniform.

CONCLUSIONS

1. The physical properties of the Kynol/Nomex fabrics were acceptable compared to the cotton fabrics except for abrasion resistance. The cotton shirting and trouser fabrics were superior to their undyed Kynol/Nomex fabric counterparts in this respect. This held true for the most part when the cotton fabrics were compared to dyed Kynol/Nomex fabrics, except in one instance, where one of the dyed Kynol/Nomex shirting fabrics was slightly better than the cotton shirting fabric in this respect.

2. Laundering tests of both the Kynol/Nomex and cotton fabrics/uniforms showed that:

a. Vertical flammability resistance was unaffected and equal for both fabric types.

b. Progressive shrinkage occurred with both fabric types to the extent that there could be potential fit problems after multiple launderings with both fabric types although in the ship tests the cotton uniform performed slightly better than the Kynol/Nomex uniforms in this respect.

c. The hand of the Kynol/Nomex fabrics changed more than the cotton fabrics (limpness) indicating some loss of the durable press finish that had been applied to the Kynol/Nomex fabrics by the manufacturer.

3. The only functional differences noted between the Kynol/Nomex and cotton uniforms in the shipboard trials were fit after laundering and comfort. Although these differences were small, fit after laundering was slightly better for the cotton uniforms; and comfort was slightly better for the LW Kynol/Nomex shirt than the HW Kynol/Nomex and cotton shirts, and slightly better for the cotton trouser than the LW and HW Kynol/Nomex trousers.

4. Preference for the cotton uniform with respect to both Kynol/Nomex uniforms in the shipboard trials was high. The cotton uniform was preferred by 3.2 to 1 over the HW Kynol/Nomex uniform which was preferred by 1.3 to 1 over the LW Kynol/Nomex uniform.

5. Physiological tests indicated there were no significant differences in heat stress indicators between the Kynol/Nomex and cotton uniforms. Subjective comments by the test volunteers rated the cotton uniform most comfortable, followed by the LW Kynol/Nomex uniform. The HW Kynol/Nomex uniform was disliked by all the test volunteers.

6. The heat resistance of the Kynol/Nomex fabrics measured as char through time for radiant heat exposures was superior to the cotton fabrics. However, in subsequent radiant heat tests to establish burn time protection provided by the fabrics it was determined that burn injury would have been sustained with the Kynol/Nomex fabrics long before char through would have occurred with the cotton fabrics at equivalent flux levels negating to some degree the value of the higher heat resistance provided by the Kynol/Nomex fabrics.

7. In radiant and flame impingement lab exposures of the Kynol/Nomex and cotton fabrics, results indicated that the times before burn injury would be sustained was directly related to the weight of the fabrics and not to their fiber composition. In no instance did the Kynol/Nomex fabrics show any unique ability to extend the time before burn injury would occur with respect to the cotton fabrics.

8. In flame envelopment and close proximity fire tests of the Kynol/Nomex and cotton uniforms the results as in the radiant and flame impingement lab exposures indicated that the degree of protection achieved was again related primarily to the weights of the uniforms and not to their fiber composition.

The HW Kynol/Nomex and cotton uniforms provided similar protection in the flame envelopment tests and were both significantly more protective than the LW Kynol/Nomex uniform. In the close proximity fire tests the cotton uniform provided significantly better protection than either Kynol/Nomex uniform.

9. Dyeing of the Kynol/Nomex fabrics to an acceptable Navy shade is feasible except colorfastness to light would always be poor because of the darkening of the Kynol fibers by ultraviolet radiation resulting in the material appearing darker.

10. The costs of employing Kynol/Nomex uniforms similar to those evaluated with the cotton uniform would be at least 2.3 times more expensive than the cotton uniform.

RECOMMENDATIONS

1. Considering the Kynol/Nomex uniforms showed no significant functional or heat protection advantages over the cotton uniform and would be at least 2.3 times more expensive than the cotton uniform, the cotton uniform should continue to be used by the Navy for its FR Shipboard Utility Uniform.

2. The Kynol/Nomex fabrics would be better utilized in applications where heat resistance rather than heat protection is the prime need.

References

1. K.W. Graves, Firefighter's Exposure Study, Cornell Aeronautical Laboratory, Inc., Dec. 1970.

2. Alice M. Stoll, et. al. Method and Rating System for Evaluation of Thermal Protection, Naval Air Systems Command, Dec. 1968.

3. Meredith M. Schoppee, et. al. Resistance of Navy Shipboard Work Clothing Materials to Extreme Heat. Albany International Research, Navy Contract No. N00140-81-C-BA83.

4. NAVEDTRA 10081-N Standard First Air Training Course, 1982.

TAB A

MATERIALS INVESTIGATION

MATERIALS INVESTIGATION

INTRODUCTION

The Navy Clothing and Textile Research Facility was tasked to assess Kynol materials for potential application in a fire retardant (FR) utility uniform. As a result of a commercial survey conducted at the onset of the program, three Kynol/Nomex blended fabrics were selected as the potential candidates.

The properties of these materials were compared to those of two fire retardant treated (FRT) cotton materials selected for a shirt/trouser utility uniform as a result of a previously conducted Fire Retardant Utility Uniform Program. The fire retardant treatment used on the cotton fabrics was tetrakis (hydroxymethyl) phosphonium hydroxide cured in a gaseous ammonia atmosphere (THPOH-NH_3), a well known durable fire retardant treatment for cotton.

This report contains information on the physical properties of the selected materials with respect to those fabric characteristics considered essential to suitable functional performance of every day wear uniforms. Properties related to color were not assessed here since the Kynol/Nomex materials were only available in their natural gold color. A parallel study (Tab E) was conducted to assess the dyeing properties of the Kynol materials.

TEST PROCEDURES

All data established for the Kynol/Nomex and cotton fabrics were determined using applicable test methods described in Federal Standard No. 191, except for the laundering tests used to establish the durability of the fire retardant properties and dimensional stability of the materials. In this case simulated shipboard launderings were performed using Standard Navy Wash Formula II (Table I). The test methods employed are shown in Table II.

TABLE I NAVY FORMULA II
HOT FORMULAS WITHOUT BLEACH (140^{o}F)

CLASSIFICATION: Cotton, Synthetic Blend Colored - Khaki Dungaree, etc.

P-D-245-C Detergent
Hard/Soft Water - Type I
Sea Water - Type II

100 lb load basis

Step	Notes	Operation	Cycle Time Minutes	Water Temp (^{o}F)	Water Level	Supplies 100 Lb Basis
1	A	Break/Suds	10	140	4"	8 oz. detergent 16 oz. alkali 2 oz. non-ionic
2		Drain	1			
3		Flush/Suds	6	140	4"	
4		Drain	1			
5		Spin	1			
6		Rinse	3	140	4"	
7		Drain	1			
8		Rinse	3	140	4"	
9		Drain	1			
10	B/C	Sour	4	120	4"	2 oz. sour blue 12 oz. instant Starch
11		Drain	1			
12		Final Spin	4			

A. Add non-ionic while water is being added
B. Bateriostats are added in this operation, if required
C. Add starch and run for 10 minutes in the manual mode when starch is required

FOR SEA WATER WASHING

Use sea water in steps 1, 3. Use Type II detergent
Use fresh water in steps 6, 8, 10

TABLE II TEST METHODS FOR DETERMINING PROPERTIES OF MATERIALS

Property	Title	Federal Standard No 191A
Weave	Visual	-----
Weight	Weight of Textile Materials; Small Specimen Method	5041
Ends/Picks Per Inch	Yarns per Unit Length in Woven Cloth	5050
Break Strength	Strength and Elongation, Breaking of Woven Cloth - Grab Method	5100
Tear Strength	Strength of Cloth, Tearing Falling Pendulum Method	5132
Air Permeability	Permeability to Air, Cloth; Calibrated Orifice Method	5450
Flammability	Flame Resistance of Cloth; Vertical	5903
Laundering Shrinkage	Mobile Laundry Evaluation for Textile Materials	5556
Abrasion	Abrasion Resistance of Cloth; Inflated Diaphram Method	5302

MATERIALS EVALUATED

Table III shows the general characteristics of the three Kynol/Nomex fabrics and the two FRT 100% cotton fabrics evaluated and their application in the test uniforms.

TABLE III MATERIALS EVALUATED

Material	Weight (oz/yd^2)	Weave	Uniform Component
70/30% Kynol/Nomex	4.5	Plain	Shirt
70/30% Kynol/Nomex	6.0	Plain	Shirt Trouser
80/20% Kynol/Nomex	8.0	Twill	Trouser
100% FRT Cotton	6.5	Chambray	Shirt
100% FRT Cotton	12.0	Denim	Trouser

RESULTS

Shirt Materials

Table IV shows the characteristics of the shirt materials evaluated. As can be seen, the Kynol/Nomex 6.0 oz/yd^2 material had a significantly higher break and tear strength in the warp direction than the Kynol/Nomex 4.5 oz/yd^2 and FRT cotton 6.5 oz/yd^2 materials. The break and tear strengths in the filling direction were similar for all materials. Air permeability was highest for the Kynol/Nomex 4.5 oz/yd^2 material and lowest for Kynol/Nomex 6.0 oz/yd^2 material with the air permeability of the cotton fabric intermediate to the two Kynol/Nomex fabrics. The low air permeability value for 6.0 oz/yd^2 Kynol/Nomex fabric could result in discomfort. Dimensional stability was best for the FRT cotton fabric as compared to both Kynol/Nomex fabrics although the values for the Kynol/Nomex materials were suitable. Abrasion resistance was significantly higher for the FRT cotton fabric. The Kynol/Nomex 4.5 oz/yd^2 material showed very poor abrasion resistance.

TABLE IV SHIRT FABRIC PROPERTIES

Physical Characteristics	Material Kynol/Nomex	Kynol/Nomex	FRT Cotton
Blend (%)	70/30	70/30	100
Weave	Plain	Plain	Plain
Weight (oz/yd^2)	4.5	6.0	6.5
Ends/Inch	54	82	76
Picks/Inch	46	45	57
Break Strength (lbs)			
Warp	104	178	110
Filling	76	85	90
Tear Strength (lbs)			
Warp	6	10	5
Filling	5	5	4
Air Permeability ($ft^3/min/ft^2$)	132	21	49
Yarn Ply	2	2	1
Dimensional Stability (%)			
Warp	2.1	1.9	1.0
Filling	2.0	1.9	0.5
Abrasion (Cycles)	280	710	1190

Trouser Materials

Table V shows the characteristics of the trouser materials evaluated. As can be seen all fabrics had suitable break and tear strengths. All fabrics had low air permeability. The cotton material had a somewhat lower air permeability than the Kynol/Nomex materials which had equivalent values. Dimensional stability was best for the cotton material, although the results for the Kynol/Nomex fabrics were considered acceptable. Abrasion resistance was substantially higher for the cotton fabric than the Kynol/Nomex materials. The Kynol/Nomex 6.0 oz/yd^2 fabric had the lowest abrasion resistance.

TABLE V TROUSER FABRIC PROPERTIES

Physical Characteristics	Material		
	Kynol/Nomex	Kynol/Nomex	FRT Cotton
Blend (%)	70/30	80/20	100
Weave	Plain	2/1 Twill	2/1 Twill
Weight (oz/yd^2)	6.0	8.0	12.0
Ends/Inch	82	74	70
Picks/Inch	45	51	43
Break Strength (lbs)			
Warp	178	174	180
Filling	85	100	104
Tear Strength (lbs)			
Warp	10	10	8
Filling	5	6	5
Air Permeability ($ft^3/min/ft^2$)	21	20	12
Yarn Ply	2	2	1
Dimensional Stability (%)			
Warp	1.9	1.9	1.2
Filling	1.9	2.0	1.0
Abrasion (Cycles)	710	1700	5000

Vertical Flame Resistance

Table VI shows the vertical flammability performance of both the shirt and trouser fabrics in a new condition and after fifteen simulated shipboard launderings using Navy Wash Formula II. Time constraints associated with the flame envelopment test schedule did not permit additional launderings. As can be seen, all of the materials displayed excellent vertical flammability resistance both new and after 15 launderings. Maximum average char lengths measured were 3.5 inches for the Kynol/Nomex materials and 3.3 inches for the cotton materials. Results of this testing showed retention of FR properties after multiple launderings.

TABLE VI VERTICAL FLAMMABILITY PERFORMANCE OF FABRICS BEFORE AND AFTER LAUNDERING

Material	Weight (oz/yd^2)	New After Flame (sec)	New After Glow (sec)	New Char Length (inch)	15 Launderings After Flame (sec)	15 Launderings After Glow (sec)	15 Launderings Char Length (inch)
70%/30% Kynol/Nomex	4.5	0	1	3.5	0	1	2.4
70/30% Kynol/Nomex	6.0	0	1	3.5	0	1	2.3
80%/20% Kynol/Nomex	8.0	0	2	3.4	0	1	2.8
FRT 100% Cotton	6.5	0	1	3.2	0	1	3.3
FRT 100% Cotton	12.0	0	1	2.9	0	1	3.0

Shipboard Laundering

To evaluate the experimental materials for progressive shrinkage and appearance after laundering, ten trousers and shirts of each material were washed in accordance with standard Navy Wash Formula II.

The following is the test procedure used to evaluate each shirt/trouser combination:

Initial waist and outseam measurements for each trouser were recorded. Also an 18 inch length and width datum line was marked on the back of each shirt.

The washing procedure for the garments was in accordance with standard Navy Wash Formula II. A washer similar to that used on ships was employed. The water temperature was 140°F. All garments were washed a total of fifteen times and dried following each wash at a temperature of 160 $\pm$ 5°F.

Measurements were recorded and appearance evaluated after the first, third, fifth, tenth and fifteenth wash/dry cycle. The shrinkage percentages as shown in Table VII reflect the average of the measurements recorded for ten garments of each material.

As shown in Table VII, it is evident that there was progressive shrinkage with the cotton chambray and denim garments as well as with the Kynol/Nomex garments. The Kynol/Nomex garments had higher initial shrinkage than the cotton garments. After fifteen launderings the shrinkage values for all garments changed significantly.

For the shirts, the cotton fabric showed significantly lower shrinkage than the Kynol/Nomex fabrics in the warp direction but greater shrinkage in the filling direction after fifteen launderings. For the trousers the 6.0 oz/yd^2 Kynol/Nomex fabric showed lower shrinkage than the cotton and 8.0 oz/yd^2 Kynol/Nomex fabric, while the cotton trouser showed less shrinkage than the 8.0 oz/yd^2 Kynol/Nomex trouser after fifteen launderings. Considering combined shrinkage in the length and width directions, poor fit would result in both the cotton and Kynol/Nomex fabrics after fifteen launderings.

It was noted that following the third wash/dry cycle that all the garments appeared to be wrinkled. Also noted was a loss of hand in the Kynol/Nomex fabrics. The wrinkled effect continued to exist on all garments for the remaining washings. Following the fifteenth wash the Kynol/Nomex garments appeared to be sleazy with a very limp, poor hand. Pilling was also noted on the Kynol/Nomex garments, especially the 4.5 and 6.0 oz/yd^2 plain weave fabrics. The chambray shirt and denim trousers also lost their initial stiff, firm hand after several launderings but this change was not as severe as occurred with the Kynol/Nomex garments.

TABLE VII GARMENT SHRINKAGE AFTER FIFTEEN SHIPBOARD LAUNDERINGS IN THE LENGTH AND WIDTH DIRECTIONS

Item	Type	Weight (oz/yd^2)	Direction	Shrinkage (%) No. of Washings 1	3	5	10	15
Shirt	Cotton	6.5	W	0.1	1.1	1.7	2.6	4.2
			F	0.8	1.0	0.9	1.6	2.8
	Kynol/Nomex	4.5	W	2.5	5.0	5.7	6.4	7.8
			F	0.2	0.2	0.2	0.6	1.5
	Kynol/Nomex	6.0	W	3.1	4.5	5.3	5.7	7.0
			F	0.3	0.4	0.7	0.9	1.8
Trouser	Cotton	12.0	WA	1.4	3.5	1.7	4.9	3.9
			IL	1.2	3.1	2.6	4.0	6.1
	Kynol/Nomex	6.0	WA	2.6	1.4	1.9	3.5	3.8
			IL	1.2	1.7	1.5	3.5	4.4
	Kynol/Nomex	8.0	WA	3.1	4.0	4.2	5.9	5.1
			IL	2.2	3.2	2.9	4.2	6.9

W = Warp
F = Filling
WA = Waist
IL = Inseam Length

CONCLUSIONS

Shirting Fabrics

1. Although the break and tear warp strength for the 6.0 oz/yd^2 Kynol/Nomex fabric was considered superior to the 4.5 oz/yd^2 Kynol/Nomex fabric and 6.5 oz/yd^2 cotton fabric, the strength values for all these fabrics was considered suitable.

2. The low air permeability of the 6.0 oz/yd^2 Kynol/Nomex fabric may render it unsuitable as a shirting fabric because of potential discomfort problems.

3. Abrasion resistance of the cotton fabric was superior to either Kynol/Nomex fabric by a factor of at least 1.7 to 1. This difference was considered significant with respect to potential wear properties.

4. Progressive shrinkage occurred with both the Kynol/Nomex and cotton fabrics. Values obtained for all materials after fifteen launderings would cause some fitting problems.

5. Multiple launderings caused pilling and loss of hand (limpness) with the Kynol/Nomex fabrics. The hand of the cotton fabric was also effected but not to the extent observed with the Kynol/Nomex materials.

Trouser Fabrics

1. All Kynol/Nomex and cotton fabrics showed similar and suitable break and tear strengths.

2. The air permeability of all the Kynol/Nomex and cotton fabrics was low, suggesting potential discomfort problems with all fabrics.

3. The abrasion resistance of the cotton fabric was superior to either Kynol/Nomex fabric by a factor of at least 2.9 to 1. This difference was considered significant with respect to wear properties.

4. Progressive shrinkage occurred with both Kynol/Nomex and cotton fabrics. Values obtained for all materials after fifteen launderings would cause some fitting problems.

5. Multiple laundering caused pilling and loss of hand (limpness) with the Kynol/Nomex fabric, particularly the 6.0 oz/yd^2 Kynol/Nomex fabric. The hand of the cotton fabric was also effected but not to the extent observed with the Kynol/Nomex fabrics.

Vertical Flammability Resistance

1. All fabrics displayed excellent vertical flammability resistance initially and after fifteen simulated shipboard launderings, indicating retention of FR properties after multiple launderings.

TAB B

SHIPBOARD EVALUATION

SHIPBOARD EVALUATION

INTRODUCTION

A shipboard evaluation was conducted to determine the acceptability and wear characteristics of Kynol/Nomex materials incorporated in the design of the standard Enlisted Man's Utility Uniform. The Kynol/Nomex uniforms, comprised of shirts and trousers, were constructed in two styles, a lightweight (LW) and a heavyweight (HW) version. These are shown in Figures 1 and 2. The uniforms were tested under shipboard conditions, along with the Navy's fire retardant treated (FRT) 100% cotton utility uniform for comparative purposes (Figure 3). Uniform performance was established through personnel questionnaire data regarding fit, comfort, appearance, launderability, durability, fire protection and preference.

SHIP EVALUATION

The ship evaluation of the test uniforms was conducted from September 1984 to November 1984 aboard four surface ships, two from the Atlantic fleet and two from the Pacific fleet.

The Atlantic fleet ships included the USS CONCORD (AFS 5) and the USS CLAUDE V. RICKETTS (DDG 5) and the Pacific Fleet ships included the USS ACADIA (AD 42) and the USS SIDES (FFG 14).

A total of 362 personnel participated in the ship evaluation. Each participant was issued two different shirt/trouser combinations to compare. Table I shows the three Kynol/Nomex and two FRT cotton materials employed, the garment form in which they were applied, and code letter assigned to each test item.

TABLE I SHIRT/TROUSER MATERIALS AND CODES
EMPLOYED IN THE SHIPBOARD EVALUATION

Material	Weave	Weight (oz/yd^2)	Code	Item
100% FRT Cotton Chambray	Plain	6.5	A	Shirt
100% FRT Cotton Denim	Plain	12.0	B	Trouser
70% Kynol/30% Nomex	Plain	6.0	C	Shirt
80% Kynol/20% Nomex	Twill	8.0	D	Trouser
70% Kynol/30% Nomex	Plain	4.5	E	Shirt
70% Kynol/30% Nomex	Plain	6.0	F	Trouser

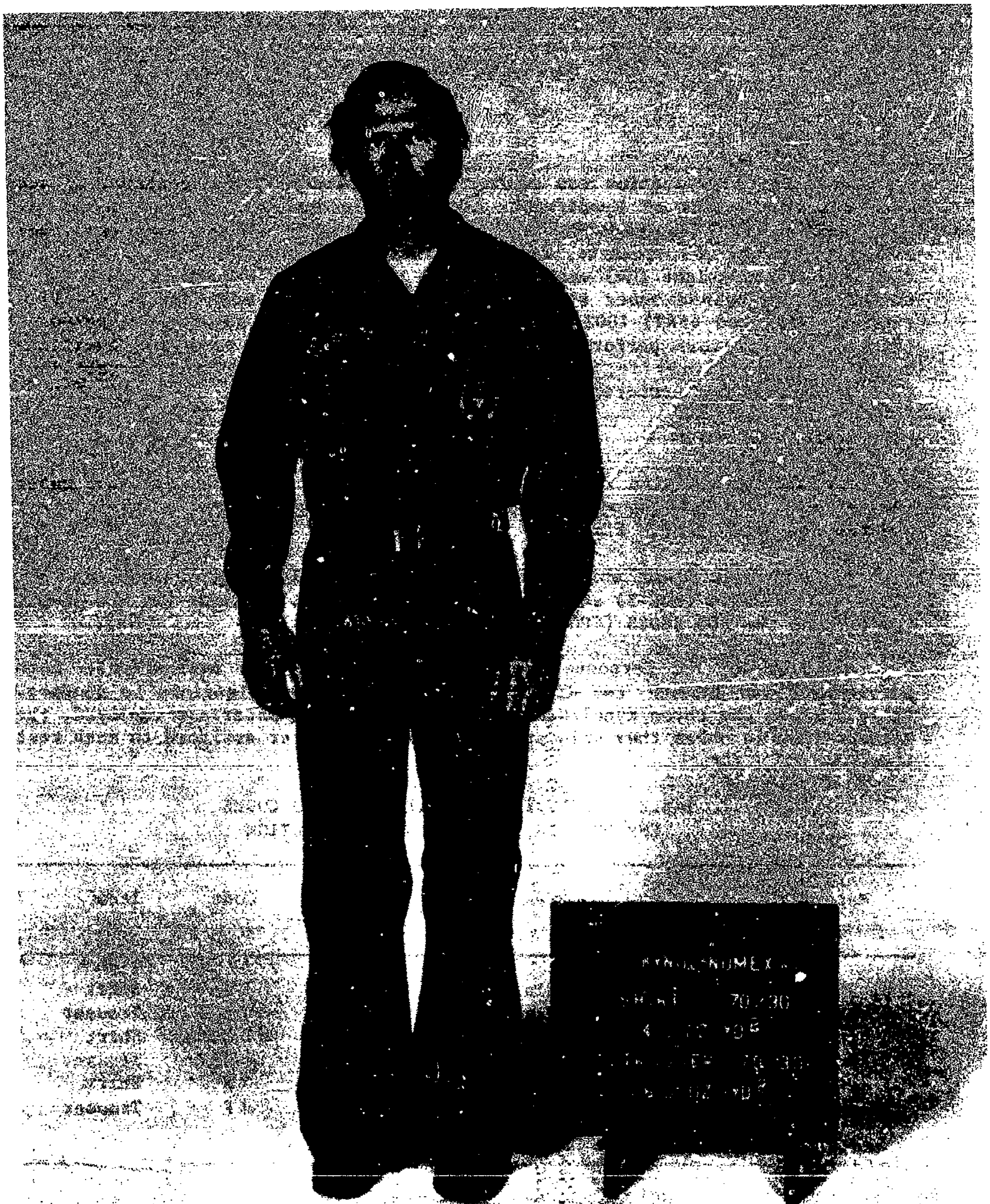


Fig. 1

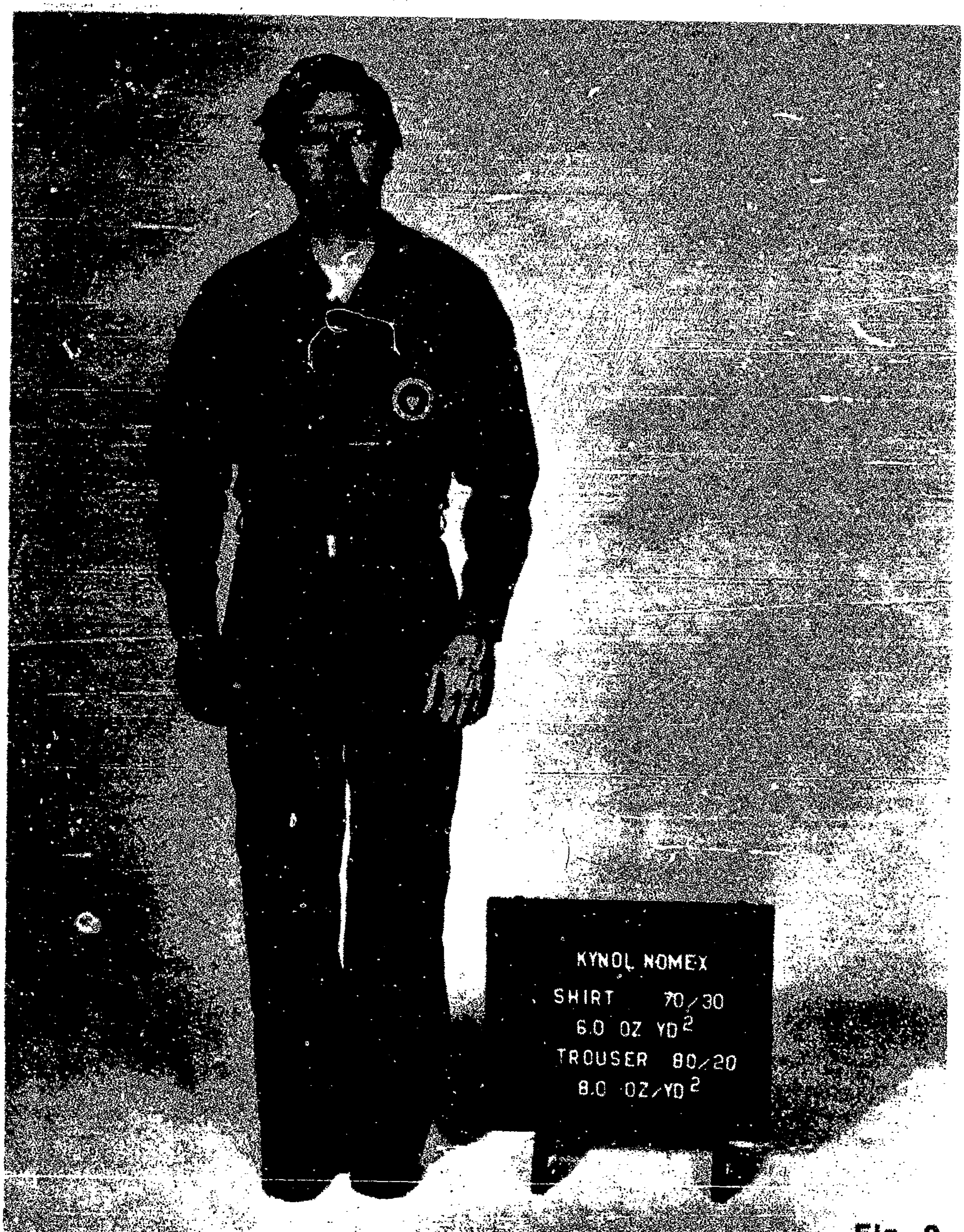


Fig. 2

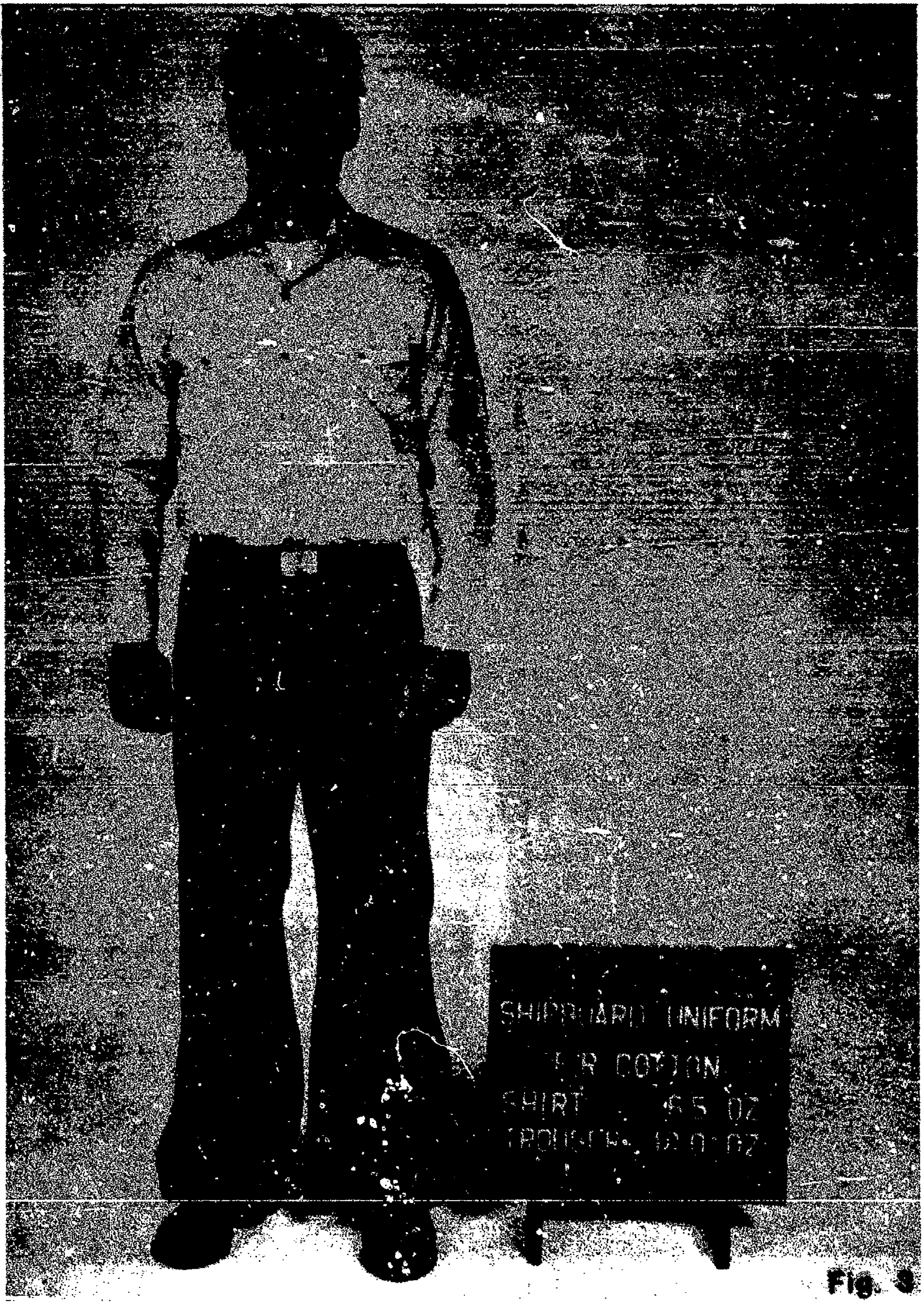


Fig. 3

Table II illustrates the uniform comparisons and the number of personnel involved in each comparison. As shown the two comparisons were the HW Kynol/Nomex uniform vs the 100% FRT cotton uniform and the HW Kynol/Nomex uniform vs the LW Kynol/Nomex uniform. Data from these comparisons were analyzed to determine which of these uniforms was most preferred and showed the best performance.

TABLE II UNIFORM COMPARISONS

Uniform	Code	vs	Uniform	Code	No. Personnel
Cotton	AB		HW Kynol/Nomex	CD	182
LW Kynol/Nomex	EF		HW Kynol/Nomex	CD	180

Each of the two uniform comparisons were evaluated separately on both an east and west coast test ship. Each designated ship was visited at the initiation of the test by Navy Clothing and Textile Research Facility (NCTRF) personnel to brief personnel on the test program and to distribute the test uniforms. Individuals that fit into the available size range of uniforms were issued two uniform combinations and instructed to wear them alternately for the 90 day test period. Every thirty days from the onset of the evaluation each test participant was instructed to complete a questionnaire (enclosure 1) relating to the fit, comfort, appearance, launderability, durability and fire protection characteristics of the test uniforms and overall preference. A test monitor was assigned aboard each ship to insure that the questionnaires were completed monthly and returned to NCTRF for tabulation.

Table III shows the responses to the monthly questionnaires recieved as well as the ships that were visited following the wear test. Not all ships were visited because of their unavailability at the end of the evaluation.

TABLE III MONTHLY QUESTIONNAIRE INPUT

Ship	Monthly Input			Follow-up Visit
	Sept	Oct	Nov	
USS CONCORD	X	X	X	
USS CLAUDE V. RICKETTS	X	X	X	X
USS ACADIA	X	X	X	
USS SIDES	X	X	X	X

Questionnaire data listed in Tables IV and V reflect the summary data received from each ship after the three month evaluation period. Following the three month evaluation, two of the four test ships were visited by NCTRF personnel to debrief personnel, examine test garments and to have test participants answer a final follow-up questionnaire (enclosure 2).

ANALYSIS OF QUESTIONNAIRE DATA

A statistical analysis was performed on all of the input data received from the ships regarding the two comparisons, the HW Kynol/Nomex uniform vs the cotton uniform (CD vs AB) and the HW Kynol/Nomex uniform vs the LW Kynol/Nomex uniform (CD vs EF).

Each test participant received two different uniform combinations for comparison. The comparisons as previously mentioned, were designed to allow selection of the most suitable materials for the utility uniform. The questionnaires required each participant to answer questions relevant to the fit, comfort, appearance, launderability, durability, fire protection, and preference for each of the uniform combinations. All test uniforms were marked with an identifying letter (Table I) to aid the participants in completing the questionnaires. Most factors addressed in the questionnaire were analyzed for each uniform component while fire protection and preference were evaluated for the total uniform.

HEAVYWEIGHT KYNOL/NOMEX VS CHAMBRAY/DENIM COMPARISON

In a previous development of a FR shipboard utility uniform, data from two wear tests[2] indicated that a 6.5 oz/yd^2, 100% FRT cotton chambray shirt and a 12.0 oz/yd^2, 100% FRT cotton denim trouser were the most preferred materials for the two piece uniform design employed. This uniform was used in this study as a standard to which the Kynol/Nomex uniforms could be compared. In this study a 6.0 oz/yd^2, 70% Kynol/30% Nomex shirt and a 8.0 oz/yd^2, 80% Kynol/20% Nomex trouser (HW Kynol/Nomex uniform) were chosen to be compared directly with the cotton uniform. A summary of the questionnaire data for this comparison is contained in Table IV.

Daily Wear

The daily wear of each uniform combination was approximately 5 to 8 days or more per month for the majority of the test participants.

Number of Times Washed Each Month and Initial Fit

All test garments were laundered in the ship's laundry using standard Navy Wash Formula II. Most were washed at least 3 to 5 times each month. Prior to washing 77% and 72%, respectively, reported the shirts and trousers for both uniforms fit properly. Most of the remaining personnel found the uniforms too big.

Appearance and Fit After Laundering

Shirts

Appearance

The test participants judged both shirts to be equivalent in appearance after laundering. Less than 10% of the personnel considered the appearance poor for either shirt. Removal of stains from each shirt was judged to be similar for both shirts. Less than 20% indicated that all stains were completely removed from both shirts.

Fit

The fit of the shirts after repeated launderings was evaluated only by the personnel indicating a satisfactory initial fit. Data showed that 81% felt the cotton shirt had a proper fit after washing while 72% indicated the Kynol/Nomex shirt had a proper fit after washing. Comments from most of those indicating an improper fit were considered nonresponsive since they indicated the clothing was too big after laundering. Lab tests showed substantial shrinkage with both type shirts after several launderings (Tab A).

Trousers

Appearance

Similar to the shirts, questionnaire responses indicated participants judged both trousers to be similar in appearance after laundering and cleanability. Less than 10% of the personnel considered the appearance poor for either trouser. Less than 15% indicated that all stains were completely removed from both trousers.

Fit

The fit of the trousers after laundering was rated by only the personnel satisfied with the initial fit. The cotton trousers were judged by 68% as fitting after laundering and the Kynol/Nomex trousers were judged as fitting properly by 55%. Regarding both types of trousers, the majority of comments pertaining to poor fit after laundering indicated the garments were too big. This was implausible since lab tests indicated substantial shrinkage of both type trousers after several launderings (Tab A).

Temperature and Comfort

The average temperature range in the work area reported by the test participants was between 71°F and 90°F. Ninety eight percent of the personnel indicated the full temperature range went from 50°F to over 90°F.

Shirts

Approximately 80% responded that both the cotton and the Kynol/Nomex shirts were either "too warm" or "too hot". The unacceptability of the shirts was also confirmed by the numerous written comments received, some even requested the shirts be short sleeve rather than the long sleeve shirt being tested. Physiological data obtained in this study and previous studies indicated that there were no statistical differences between these uniforms and the current polyester/cotton utility uniform regarding heat stress (Tab C).

Data revealed a high percentage of the test population experienced some degree of irritation from both shirt fabrics. This condition appeared to decline with repeated washings. The final percentages were; 68% experienced no irritation from wearing the cotton shirt while 54% reported no irritation while wearing the Kynol/Nomex shirts.

Trousers

The comfort comparison for the cotton verses the Kynol/Nomex trouser indicated neither trouser was well accepted. Only 42% of the participants responded that the cotton trousers were "just right" and only 32% indicated the Kynol/Nomex trousers were "just right". Complaints that the trousers were "too warm" or "too hot" were indicated by 57% of the participants for the cotton trousers and by 66% for the Kynol/Nomex trousers. Physiological tests indicated the heat stress associated with these items was similar to the current polyester/cotton utility uniform.

Response to the question of the trousers irritating the skin showed that 69% felt the cotton trouser did not irritate their skin and 56% replied that the Kynol/Nomex trouser did not irritate their skin. These final percentages were lower than the initial comments received, indicating that this condition diminished after washing.

<u>Durability</u>

Shirts

The durability of the shirts was judged on material wear and on tears in the material and in the garment seams. Monthly questionnnaire data showed clearly that both shirts showed some progressive wear. Relative to both shirts, about 87% of the test participants indicated "very little" to "some" wear. In regards to tearing, 95% of the participants for the cotton and 91% for the Kynol/Nomex shirt responded that no tearing was noted. Most of the minor reports of tears indicated that the material tore as opposed to the seam tearing.

Trousers

The trousers were evaluated for durability for the same parameters as the shirts. The monthly questionnaire data showed a trend of some progressive wear on the trousers following repeated wash and wear. About 85% reported seeing "very little" to "some" wear on both the trousers after three months. At least 87% of the test participants reported neither the cotton nor the Kynol/Nomex trousers tore. The majority of the personnel that responded to the contrary reported the material tore.

Fire Protection

None of the data collected indicated any major instance which would have fully evaluated the fire retardant properties of the garments. Some participants reported coming in contact with either sparks or high temperature sources. At least 65% of the personnel reported no exposure to flames, sparks or high temperature with either uniform. Of those that reported some type of exposure, approximately 65% felt that both uniforms offered "excellent" to "good" protection.

Preference

The questionnaire data clearly reflects that test participants preferred the cotton uniform by 3 to 1 over the Kynol/Nomex uniform even though responses for individual characteristics indicated small differences between the uniforms.

TABLE IV FRT COTTON CHAMBRAY AND DENIM UNIFORM VS HEAVYWEIGHT KYNOL/NOMEX UNIFORM

Characteristic		Cotton Uniform Shirt A	Cotton Uniform Trouser B	Kynol/Nomex Uniform Shirt C	Kynol/Nomex Uniform Trouser D
Temperature ^{o}F (%)	Below 50		2		
	50 - 70		20		
	71 - 90		56		
	Above 90		22		
Initial Fit Proper (%)	Yes	78	73	76	72
	No	22	27	24	28
Initial Fit Problem (%)	Too Short	19	10	26	32
	Too Long	22	38	19	21
	Too Loose	47	47	36	32
	Too Tight	12	5	19	15

TABLE IV (CONT'D)

Characteristic		Cotton Uniform Shirt A	Cotton Uniform Trouser B	Kynol/Nomex Uniform Shirt C	Kynol/Nomex Uniform Trouser D
Times Garments Worn per Month (%)	0 - 4	30		30	
	5 - 8	43		47	
	9 - 10	18		15	
	Over 12	9		8	
Comfort (%)	Too Hot	29	18	33	25
	Too Warm	51	39	48	41
	Just Right	19	42	18	33
	Too Cool	1	1	1	1
Skin Irritation (%)	Not at All	68	69	54	56
	A Little	20	21	27	27
	Somewhat	11	9	15	13
	Very	1	1	4	4
# Times Washed (%)	0 - 2	23	22	27	27
	3 - 5	51	52	46	46
	6 - 8	25	25	21	21
	over 8	1	1	6	
Fit After Laundering Proper (%)	Yes	81	68	73	55
	No	19	32	27	45
Fit After Laundering Problem (%)	Too Short	22	9	27	31
	Too Long	18	36	14	16
	Too Loose	49	46	35	29
	Too Tight	11	9	24	24
Appearance After Laundering (%)	Excellent	9	10	8	8
	Good	58	59	58	58
	Fair	28	27	28	28
	Poor	5	4	6	6

TABLE IV (CONT'D)

Characteristic		Cotton Uniform Shirt A	Cotton Uniform Trouser B	Kynol/Nomex Uniform Shirt C	Kynol/Nomex Uniform Trouser D
Grease and Stain Removal (%)	Completely	15	14	12	12
	Almost Completely	29	31	30	30
	Partially	46	44	47	47
	Not at All	10	11	11	11
Tear (%)	Did Not Tear	95	91	91	87
	Seam Tore	1	3	3	3
	Material Tore	4	6	6	10
Wear (%)	Very Little	55	52	58	56
	Some	33	33	29	30
	Moderate	12	14	12	13
	Excessive	0	1	1	1
Exposure (%)	None	65		66	
	Flames	5		5	
	Sparks	8		7	
	High Temperature	22		22	
Exposure Protection (%)	Excellent	9		10	
	Good	56		57	
	Fair	29		28	
	Poor	6		5	
Preference (%)		76		24	

HEAVYWEIGHT KYNOL/NOMEX UNIFORM VS LIGHTWEIGHT KYNOL/NOMEX UNIFORM

To assess the characteristics of lighter weight Kynol/Nomex fabrics for utility uniforms the following weight Kynol/Nomex fabrics were included in the shipboard wear test; a 4.5 oz/yd^2, 70% Kynol/30% Nomex shirt and 6.0 oz/yd^2, 70% Kynol/30% Nomex trouser. These were compared to the 6.0 oz/yd^2, 70% Kynol/30% Nomex shirt and 8.0 oz/yd^2, 80% Kynol/20% Nomex trouser evaluated against the FRT cotton uniform. A summary of the questionnaire data is contained in Table V.

Daily Wear

The daily wear for each uniform type was approximately 5 to 8 or more days per month for the majority of the test participants.

Number of Times Laundered and Initial Fit

Each shirt/trouser combination was washed in the ship's laundry using standard Navy Wash Formula II an average of 3 to 5 times per month. Initial fit of the uniforms was reported acceptable by approximately 78% for both uniforms. A similar number of the remaining personnel found the shirts either too big or too small while the majority of these participants found the trousers too small.

Appearance and Fit after Laundering

Shirts

Appearance

In evaluating the shirts for appearance after laundering at least 60% of the participants rated the appearance of both Kynol/Nomex shirts similarly as "good" to "excellent". Only 5% thought the appearance was poor. The ability to remove stains was similar as well for both shirts. Only 15 to 17% indicated that stains were completely removable.

Fit

The fit after laundering of both shirts was very similar. According to those personnel reporting an acceptable initial fit, 75 to 78% considered both shirts to be an acceptable fit after laundering. Of those indicating poor fit, at least 39% indicated the uniforms were too big which is not plausible since these materials demonstrated significant shrinkage after several launderings in lab tests (Tab A).

Trouser

Appearance

Both Kynol/Nomex trousers were judged by about 56% of the test personnel to have "excellent" to "good" appearance after washing. The removal of stains was judged similarly for both trousers. Only 14 to 17% indicated that stains were completely removed.

Fit

Fifty two percent of the participants who rated the initial fit of the trousers acceptable indicated they fit properly after repeated launderings. Most of the remaining population (82%) indicated the trousers were too tight or too short.

Comfort

Shirts

Fifty four percent of the participants judged the LW shirt as comfortable while 46% judged the HW shirt as comfortable. Most of the remaining personnel judged the shirts to be either "too warm" or "too hot".

At least 49% reported that the shirts caused some level of irritation to the skin, but noted this condition to diminish with repeated launderings.

Trousers

The trouser comfort ratings were similar to the shirts. About 55% found the LW trouser comfortable while 49% found the HW trouser comfortable. Most of the remaining participants judged both trousers as being "too warm" or "too hot".

Assessing fabric skin irritation, at least 49% of the personnel noted some degree of skin irritation while wearing both trousers. As with the shirts, participants indicated that the irritation diminished following repeated washings.

Durability

Shirts

The two shirts were evaluated for durability after wearing and washing and more specifically for tears in the material itself or of the garment seams. Both shirts were judged similar with 59% reporting "very little" wear. Approximately 83% reported no tears in either shirt. For the HW shirt 6% indicated tears at the seams and 11% reported tears in the material, while a similar number (8%), reported tears in the seam and the material for the LW shirt.

Trousers

The trousers were evaluated for wear and tear as were the shirts. For the HW trousers 57% reported "very little" wear and 59% reported the same for the LW trousers. At least 78% reported that neither of the trousers tore while similar percentages of the remaining personnel reported that both trousers either tore at the seams or in the fabric.

Fire Protection

Approximately 65% of the participants reported no exposure to flames, sparks or high temperatures while wearing the Kynol/Nomex uniforms. For the others there was no significant incident indicated which would have tested the fire protection qualities of the garments. The majority (56 to 58%) of those reporting exposure to flames, sparks or high temperature felt that protection was "good" to "excellent" for both uniforms.

Preference

The preference between the different weight Kynol/Nomex uniforms was not substantial. Only 46% preferred the HW uniform while 36% chose the LW uniform. The remaining personnel (18%) did not chose either uniform. Comments from these personnel indicated that neither of the uniform combinations was acceptable. Responses to the individual characteristics indicated very few functional differences between the two uniforms.

TABLE V HEAVYWEIGHT KYNOL/NOMEX UNIFORM VS LIGHTWEIGHT KYNOL/NOMEX UNIFORM

Characteristic		HW Uniform Shirt C	HW Uniform Trouser D	LW Uniform Shirt E	LW Uniform Trouser F
Temperature ^{o}F (%)	Below 50		5		
	50 - 70		32		
	71 - 90		50		
	Above 90		13		
Initial Fit Proper (%)	Yes	79	78	77	79
	No	21	22	23	21
Initial Fit Problem (%)	Too Short	30	42	28	38
	Too Long	9	11	12	16
	Too Loose	40	11	44	15
	Too Tight	21	36	16	31

TABLE V (CONT'D)

Characteristic		HW Uniform Shirt C	HW Uniform Trouser D	LW Uniform Shirt E	LW Uniform Trouser F
Times Garments Worn Per Month (%)	0 - 4	23		27	
	5 - 8	55		55	
	9 - 10	16		13	
	Over 12	6		5	
Comfort (%)	Too Hot	14	13	12	10
	Too Warm	39	36	32	31
	Just Right	46	49	54	55
	Too Cool	1	2	2	4
Skin Irritation (%)	Not at all	49	49	51	51
	A little	31	33	29	30
	Somewhat	12	13	15	14
	Very	8	5	5	5
# Times Washed (%)	0 - 2	36	37	38	37
	3 - 5	49	48	47	48
	6 - 8	10	10	9	9
	Over 8	5	5	6	6
Fit After Laundering Proper (%)	yes	75	66	78	66
	No	25	34	22	34
Fit After Laundering Problem (%)	Too Short	27	43	20	44
	Too Long	8	9	10	9
	Too Loose	31	9	46	9
	Too Tight	24	39	24	38
Appearance After Laundering (%)	Excellent	3	7	9	7
	Good	52	52	53	49
	Fair	35	36	33	39
	Poor	5	5	5	5

TABLE V (CONT'D)

Characteristic		HW Uniform Shirt C	HW Uniform Trouser D	LW Uniform Shirt E	LW Uniform Trouser F
Grease and Stain Removal (%)	Completely	15	14	17	17
	Almost Completely	37	36	35	35
	Partially	39	40	39	39
	Not at all	9	10	9	9
Tear (%)	Did not tear	83	78	84	80
	Seam tore	6	11	8	10
	Material tore	11	11	8	10
Wear (%)	Very Little	59	57	59	59
	Some	28	31	28	27
	Moderate	11	10	11	11
	Excessive	2	2	2	3
Exposure (%)	None		65		67
	Flames		8		6
	Sparks		4		4
	High Temperature		23		23
Exposure Protection (%)	Excellent		11		10
	Good		47		46
	Fair		38		40
	Poor		4		4
Preference (%)	HW			46	
	LW			36	
	None			18	

FOLLOW UP VISIT

At the completion of the evaluation, two of the four ships involved in the wear test were visited by NCTRF personnel to debrief test participants, have them answer a final questionnaire (enclosure 2) and obtain samples of worn garments for further investigation. Both ships visited tested the HW Kynol/Nomex uniform against the LW Kynol/Nomex uniform. The information obtained from these visits supported the monthly questionnaire data.

Generally, the uniform that was preferred depended upon the temperature of the work space the individual was in while wearing the uniform. Thus the HW uniform was preferred by those working in a cool area or climate and the LW uniform was preferred for the warmer temperatures and engine room work areas.

Negative comments regarding the Kynol/Nomex uniforms included difficult to iron, grease and oil stains difficult to remove and some initial skin irritation. Other comments were; a blue color uniform would be preferred as well as short sleeve shirts.

CONCLUSIONS

The wear test evaluation clearly showed that the 100% FRT cotton chambray shirt and denim trousers were the most highly accepted uniform combination. This combination was chosen 3 to 1 over the HW Kynol/Nomex uniform, which was chosen by 46% to 36% over the LW Kynol/Nomex uniform. Both the cotton uniform and the HW Kynol/Nomex uniforms were equally rated for comfort and appearance. The only characteristics in which there was some differences between the cotton and Kynol/Nomex uniforms were skin irritation and fit after laundering. For each of these characteristics the cotton material was judged to be less irritating (68% to 55%) and to have better fit after laundering (81% to 73% for the shirts and 68% to 55% for trousers).

The comparison of the two Kynol/Nomex uniforms was not as decisive and questionnaire data revealed that both weight uniforms were regarded basically the same for comfort, durability, launderability, and fire protection. From the follow-up ship visit it was concluded that the temperature of the work area was the key factor in determining where each uniform was more acceptable, not one being acceptable for all work spaces.

Considering all the questionnaire data and personal interviews, the greater acceptability of the 100% FRT cotton chambray shirt and denim trouser uniform over both Kynol/Nomex uniforms (3 to 1) was not supported by the differences seen in the data for individual characteristics. However, there was certainly a concensus for the cotton uniform based on the preference data.

TAB C

PHYSIOLOGICAL EVALUATION OF KYNOL/NOMEX UTILITY UNIFORMS

PHYSIOLOGICAL EVALUATION OF KYNOL UTILITY UNIFORMS

INTRODUCTION:

A physiological evaluation was performed to establish the heat stress characteristics of Kynol/Nomex uniforms with respect to the FRT cotton utility uniform previously evaluated for shipboard use. The evaluation was aimed at assessing the potential additional heat stress imposed by both a lightweight (LW) Kynol/Nomex uniform and a heavyweight (HW) Kynol/Nomex uniform as compared to a fire retardant treated (FRT) cotton uniform while worn in hot environments.

TEST PLAN:

The heat stress imposed by the test uniforms was evaluated by comparing the cotton uniform to the two Kynol/Nomex uniforms at three environmental conditions: 70°F, 50% RH; 95°F, 70% RH; and 120°F, 20% RH. The average work load was 232 watts/m^2 and represented a moderate work activity.

METHODS AND PROCEDURES:

Eight men, who were deemed physically fit and had had no previous heat-related injuries, were selected from the USANRDC test subject platoon and consented to participate in this study. Their mean (±S.E.) physical characteristics are as follows: age - 25.1 ± 1.8 years; height - 175.3 ± 9.8 cm; weight - 78.5 ± 9.9 kg; surface area - 1.94 ± 0.18 m^2. All subjects were evaluated while wearing each of the following three types of utility ensembles:

1. FRT cotton two-piece utility uniform consisting of 6.5 oz/yd^2 chambray shirt and 12.0 oz/yd^2 denim trousers.

2. HW Kynol/Nomex two-piece utility uniform consisting of 6.0 oz/yd^2, 70/30% Kynol/Nomex shirt and 8.0 oz/yd^2, 80/20% Kynol/Nomex trousers.

3. LW Kynol/Nomex two-piece utility uniform consisting of 4.5 oz/yd^2, 70/30% Kynol/Nomex shirt and 6.0 oz/yd^2, 70/30% Kynol/Nomex trousers.

Each ensemble was worn over underwear and with shoes and socks. The order of testing was randomized for each clothing/environment combination.

Testing was conducted in three different environments. 21.1°C, 50% r.h.; 35.0°C, 70% r.h.; and 48.9°C, 20% r.h. All exposures were two hours in duration with each hour consisting of 10 minutes rest and 50 minutes work (treadmill walking at 1.56 m/s, 0% grade).

Prior to the experimental sessions, the subjects, clothed in the standard FR Navy utility clothing, underwent five days of exposure to alternating hot-dry (48.9°C, 20% r.h.) and hot-humid (37.8°C, 70% r.h.) environments to assure adaptation to heat. The work-rest cycle was the same as that for the experimental sessions.

Preparation for all tests was the same. Prior to each heat exposure, the test volunteer was weighed nude, inserted with the rectal probe (Y.S.I. thermistor) and then dressed for the test. Copper-constantan thermocouples were attached to the skin surface at the chest, forearm, and calf, Mean skin temperature was then determinated by appropriately weighted constants. Three electrodes were attached to the surface of the chest for monitoring heart rate via the EKG. After the appropriate clothing ensemble has been donned, a clothed weight was obtained.

Rectal and skin temperatures were monitored continuously on a Hewlett-Packard data acquisition system. Heart rate was counted from the telemetered EKG trace every 10 minutes. Sweat and evaporation rates were determined by changes in nude and clothes body weights, respectively, after adjusting for water intake. Water intake was encouraged and was permitted ad libitum. Metabolic rate was determined by having the subjects breathe into Douglas bags; the expired air was then analyzed for O_2 and CO_2 content and the volume of air was measured with a spirometer.

Exposures were planned to be two hours in duration. However, the test was terminated if any of the following occurred: rectal temperature exceeding 39.5°C or 39.2°C during work or rest, respectively; heart rate greater than 180 or 140 beats/min during work or rest, respectively; rectal-skin temperature crossover; nausea, syncope, dry skin, or subjective distress.

RESULTS AND DISCUSSION:

The average workload at 1.56 m/s, 0% grade was 232 $\pm$ 11 Watts/m^2 (1.30 liters/min). This rate of energy expenditure is considered moderate and is equivalent to tasks such as: marching at 1.34 m/s with a 27-kg load, shoveling an 8-kg load of gravel at 12 throws/min, digging trenches, and marking with a rifle.

For all environment/clothing combinations, each subject successfully completed the two-hour heat exposures without undue heat stress. The half-hourly course for rectal temperature is depicted for the clothing ensembles in each environment in Figures 1 through 3. Regardless of the environmental conditions, all ensembles displayed identical rises in core temperature over the duration of the test. Final rectal temperature averaged 37.71, 38.51, and 38.39°C in the 21.1, 35.0, and 48.9°C environments, respectively. The rate of rise of rectal temperature over the last hour was 0.43 and 0.35°C/h for the 35.0 and 48.9°C environments, respectively. At this rate, core temperature would rise to critical levels in about two hours for each of the ensembles. However, as core temperature is greater than 38.2°C, which is the value considered comfortable for work of duration longer than 3 hours, individuals would be expected to experience some degree of discomfort from continued work in the heat. These environments are considered beyond the "prescriptive zone" for long-term (up to 8 hours) work.

Figures 4 through 6 present the average $\pm$ values for the mean weighted skin temperatures for each clothing/environment combination. As with the rectal temperature, there were no significant differences in skin temperature resulting from the clothing ensembles in any of the three environments. Skin temperatures followed similar response patterns regardless of the clothing tested.

The difference between the rectal and skin temperatures was calculated to provide an indication of the gradient available for heat transfer from the core to the periphery. Since there were no significant differences in rectal or skin temperature due to clothing ensemble, there were obviously no differences in the calculated gradient. In the comfortable 21.1°C environment, the gradient for heat dissipation increased from 4.1 to 6.3°C over the 120-min exposure. In the hot-humid environment, the gradient remained somewhat stable over the two hours at approximately 1.8°C. Similarly, in the hot-dry climate, the gradient stabilized at approximately 1.5°C throughout the two-hour exposure.

Heart rate responses to the two-hour heat exposure are presented in Figures 7 through 9. Again, there were no significant differences in heart rate resulting from the different clothing ensembles. Heart rate changed only with the environment in which the garments were evaluated. Final heart rate averaged 98, 140, and 136 beats/min for all three ensembles in the 21.1, 35.0 and 48.9°C environments, respectively.

Figure 10 presents the mean $\pm$ S.E. for the sweat and evaporation rates for each environment/clothing combination. For the three environments, sweat rate changed as a result of the environment and not the clothing ensemble. At 21.1°C, the average sweat rate was 132 Watts/m^2, which was significantly lower than the 448 Watts/m^2 measured in the hot-humid and hot-dry environments. There was no difference in sweat output between the later two climates. Evaporation rate similarly was the same for each clothing ensemble. However, evaporation occurred at a significantly more rapid rate in the hot-dry than in the hot-humid environment. Evaporation rate averaged 107, 211, and 314 Watts/m^2 in the 21.1, 35.0 and 48.9°C environments, respectively.

The evaporation to sweat ratio represents the proportion of secreated sweat that is evaporated. This ratio, therefore, can give some indication of the permeability of the garment to water transfer. At 21.1°C, the Evap/Sweat ratios = 0.76, 0.82, and 0.88 for the FRT cotton, HW and LW Kynol/Nomex ensembles, respectively ($p>0.05$). In the hot-humid environment, the FRT cotton uniform demonstrated a significantly lower Evap/Sweat ratio than either the HW or LW Kynol/Nomex ensembles, which were similar to each other (0.41 for FRT cotton versus 0.50 for HW and LW Kynol/Nomex). At 48.9°C, the Evap/Sweat ratios were 0.68, 0.71, and 0.73 for the FRT cotton, HW, and LW Kynol/Nomex uniforms, respectively.

Subjectively, the eight volunteers preferred the FRT cotton uniform to either of the two experimental Kynol ensembles. Other than the somewhat itchy fabric, the LW Kynol/Nomex ensemble was thought to be very comfortable in the hot temperatures. The HW Kynol/Nomex ensemble was disliked by all test volunteers. They found it too heavy, very itchy, and when wet from sweating, more burdensome than any of the other ensembles.

CONCLUSIONS:

1. No significant differences in tolerance time, rectal temperature, skin temperature, heart rate, evaporation rate, and sweat rate were found among the three uniforms evaluated. Individual performance was not affected by the clothing worn.

2. In the hot-humid environment (95°F, 70% RH) a significantly higher evaporation/sweat ratio was found for the Kynol/Nomex uniforms (.50) as compared to the FRT cotton uniform (.41). This ratio gives some indication of the water vapor permeability of the garment to total sweat production. The Kynol/Nomex uniforms were more efficient than the cotton uniform in this respect. The higher moisture retention of the cotton fabrics contributed to this difference.

3. Based on subjective comments, the most comfortable ensemble was the FRT cotton uniform, followed by the LW Kynol/Nomex ensemble. The HW Kynol/Nomex ensemble was disliked by all 8 volunteers.

FIGURE 1

RECTAL TEMPERATURE

21.1 deg C / 50% R.H.

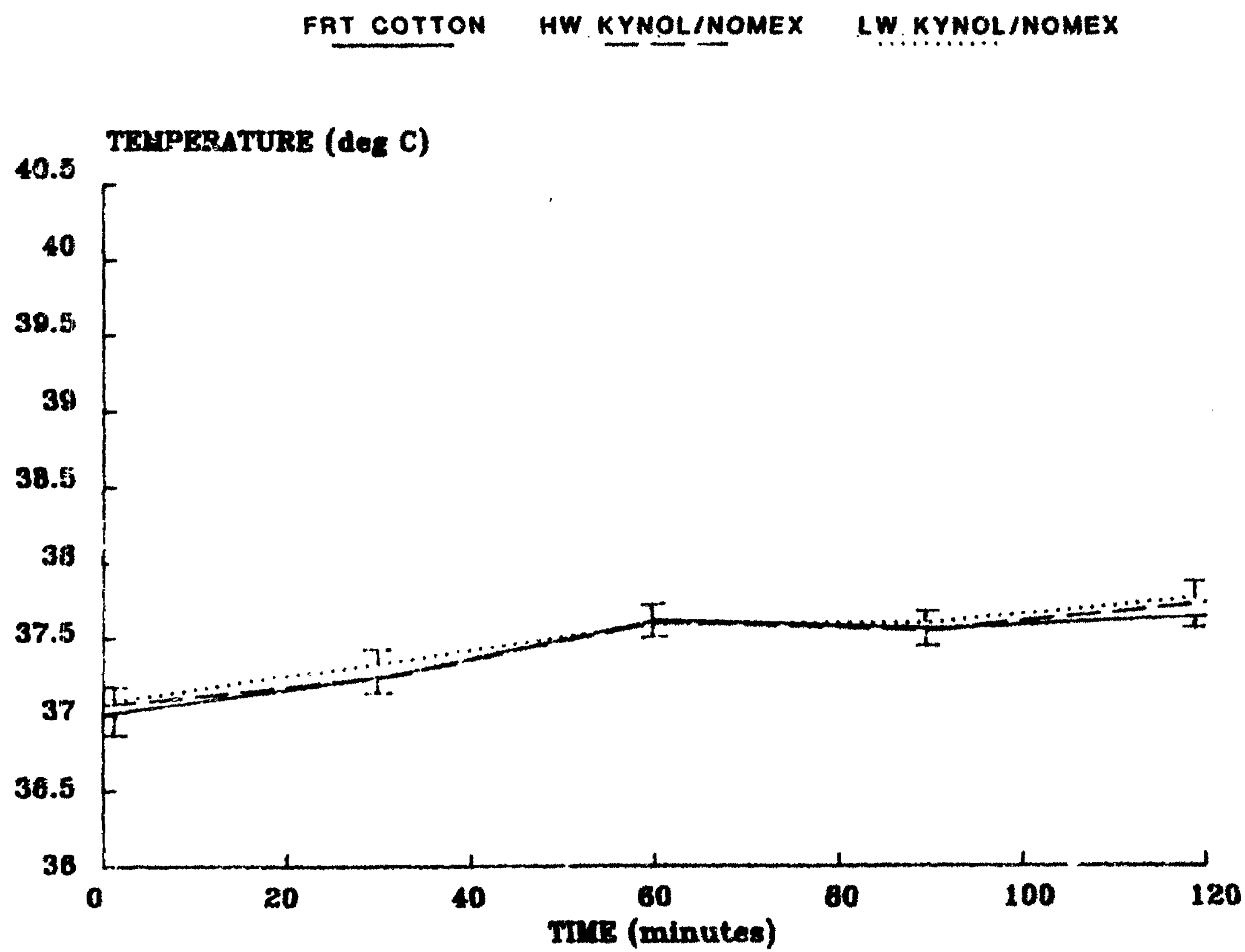


FIGURE 2

RECTAL TEMPERATURE

35.0 deg C / 70% R.H.

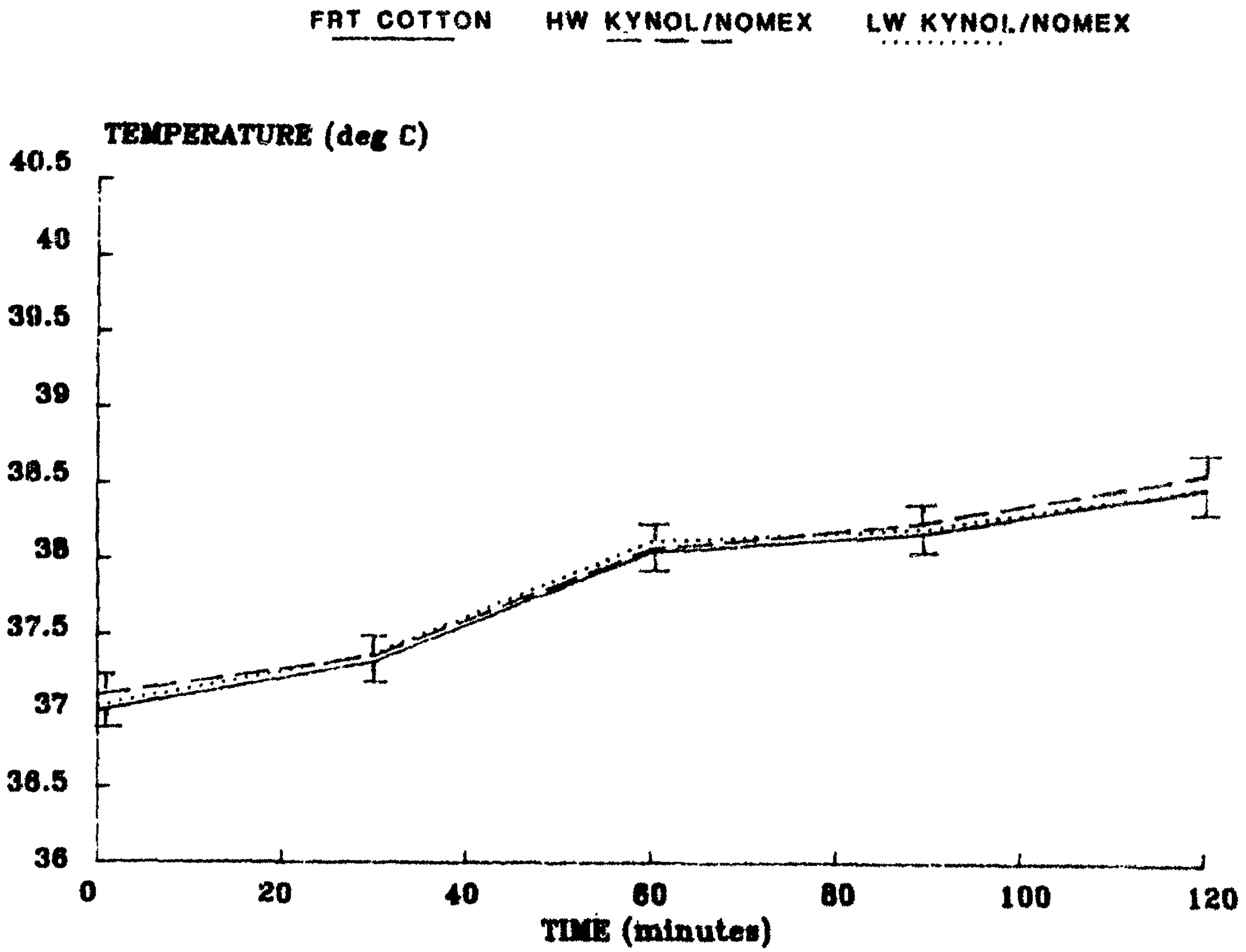


FIGURE 3
RECTAL TEMPERATURE
48.9 deg C / 20% R.H.

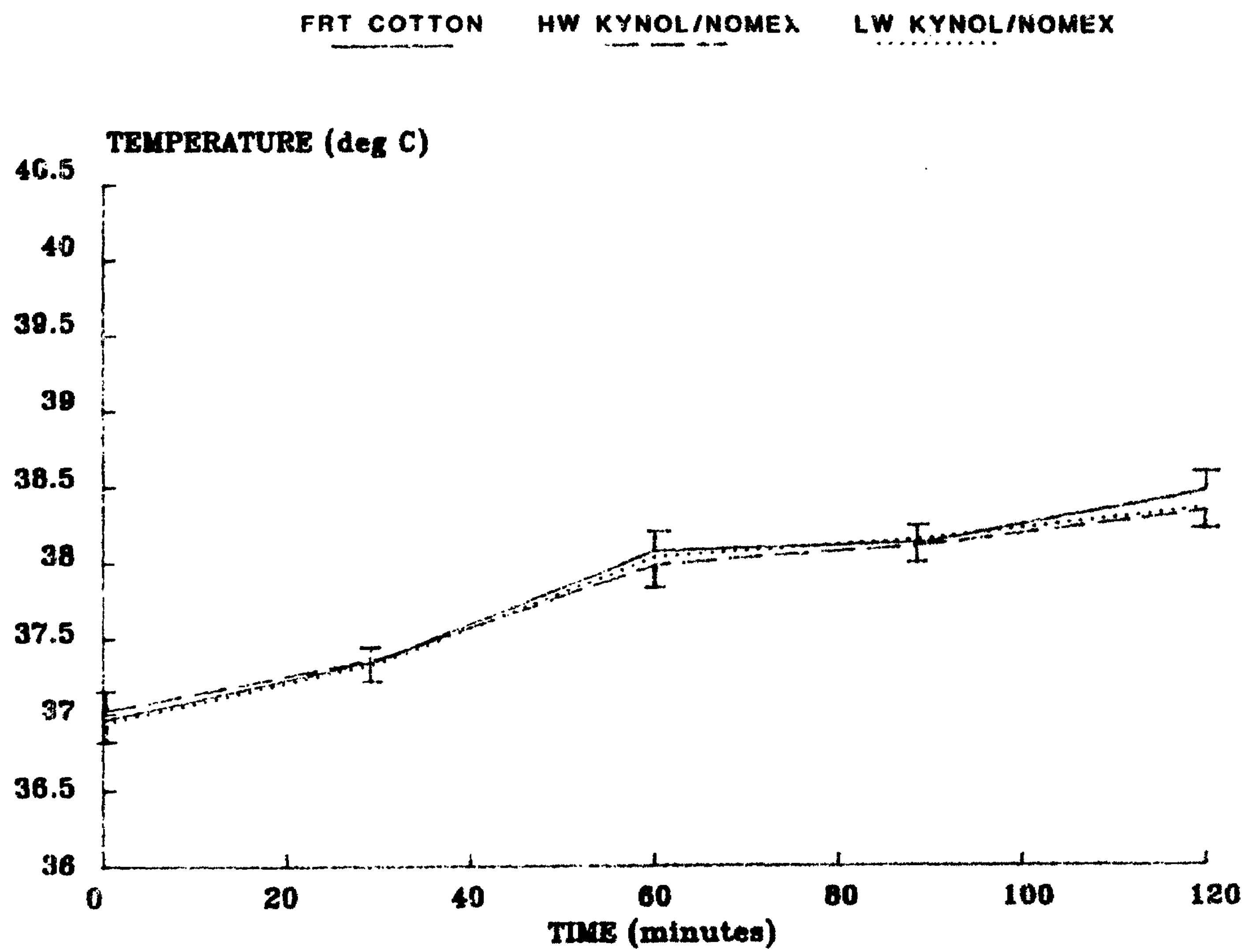


FIGURE 4

MEAN WEIGHTED SKIN TEMPERATURE

21.1 deg C / 50% R.H.

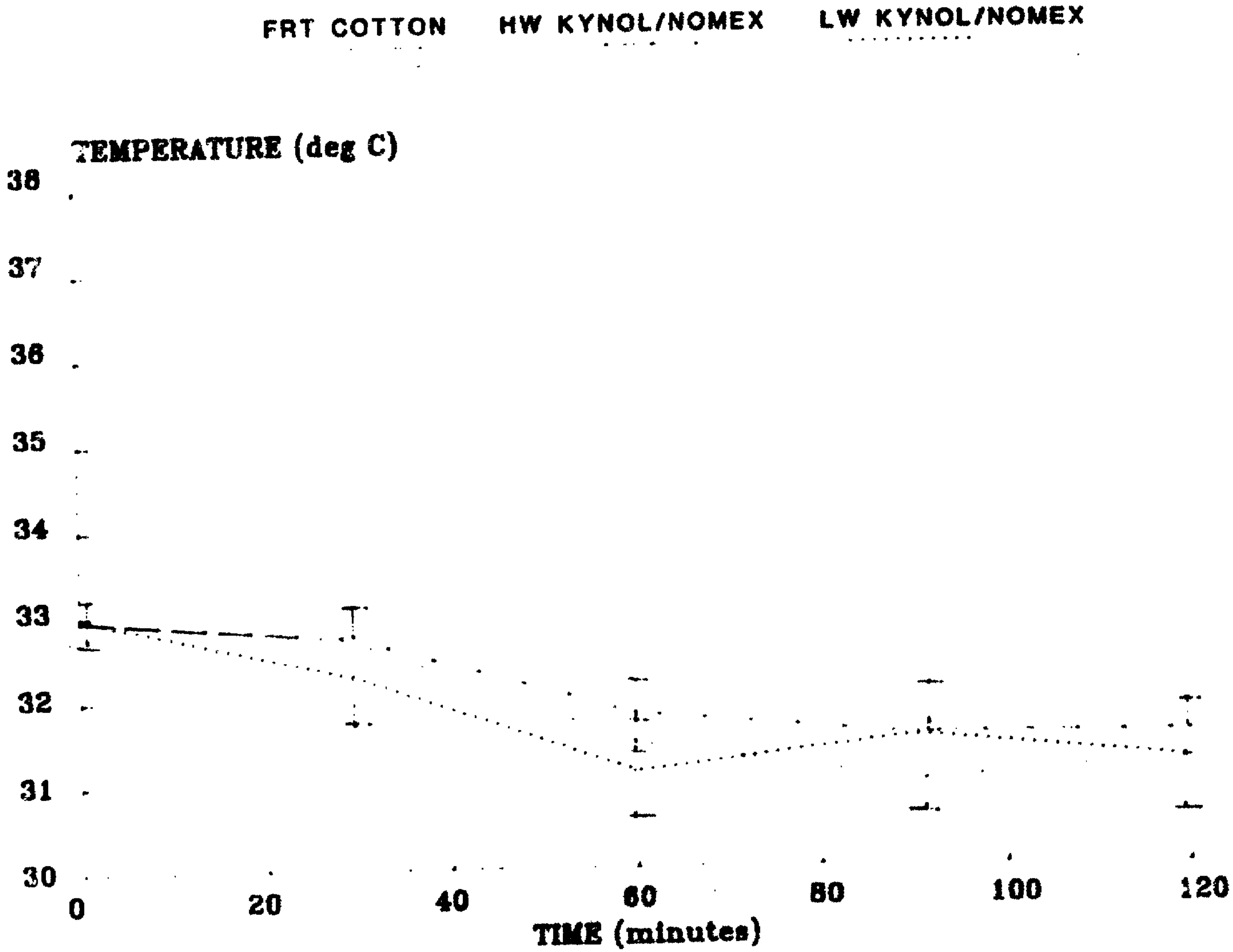


FIGURE 5

MEAN WEIGHTED SKIN TEMPERATURE

35.0 deg C / 70% R.H.

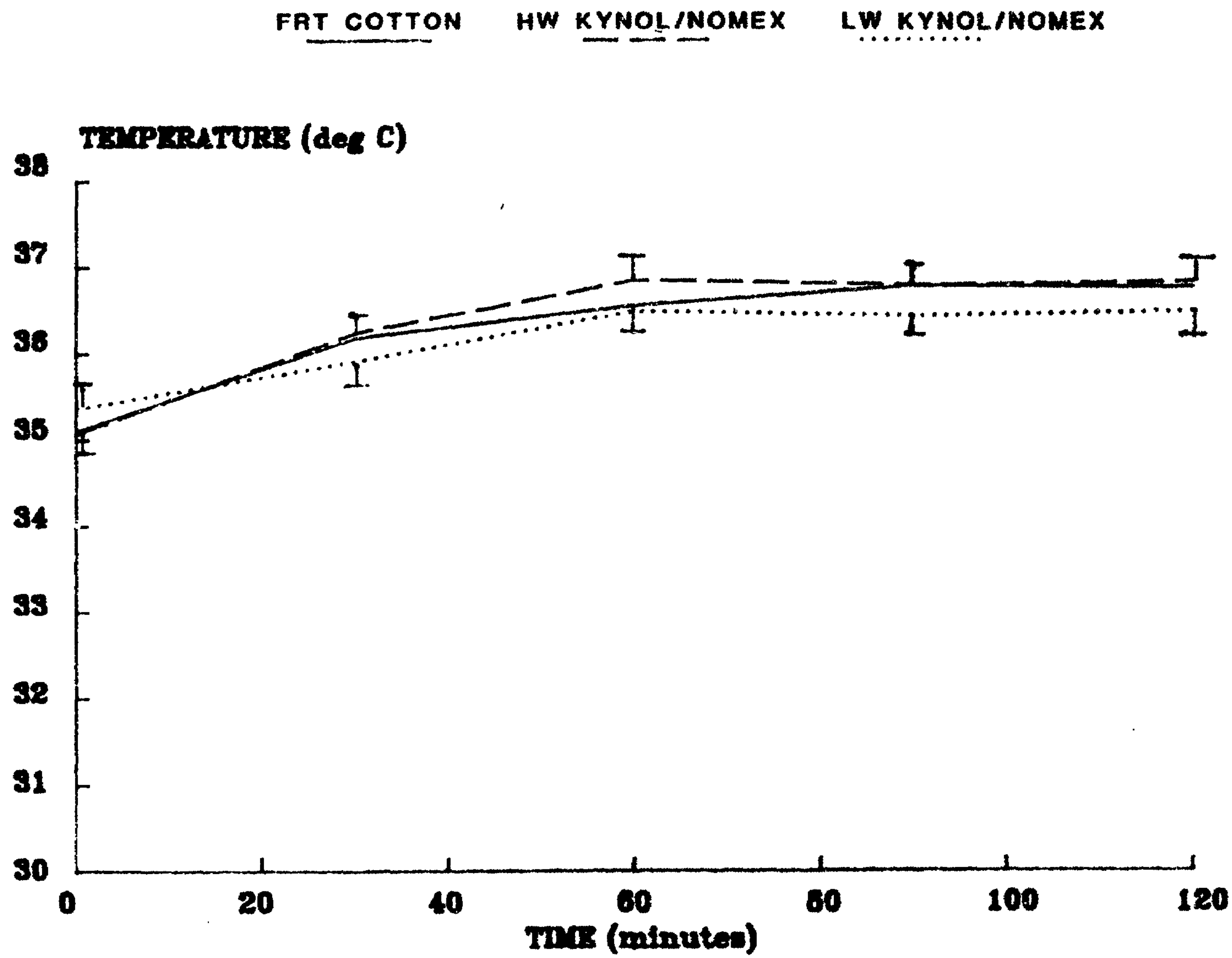


FIGURE 6

MEAN WEIGHTED SKIN TEMPERATURE

48.9 deg C / 20% R.H.

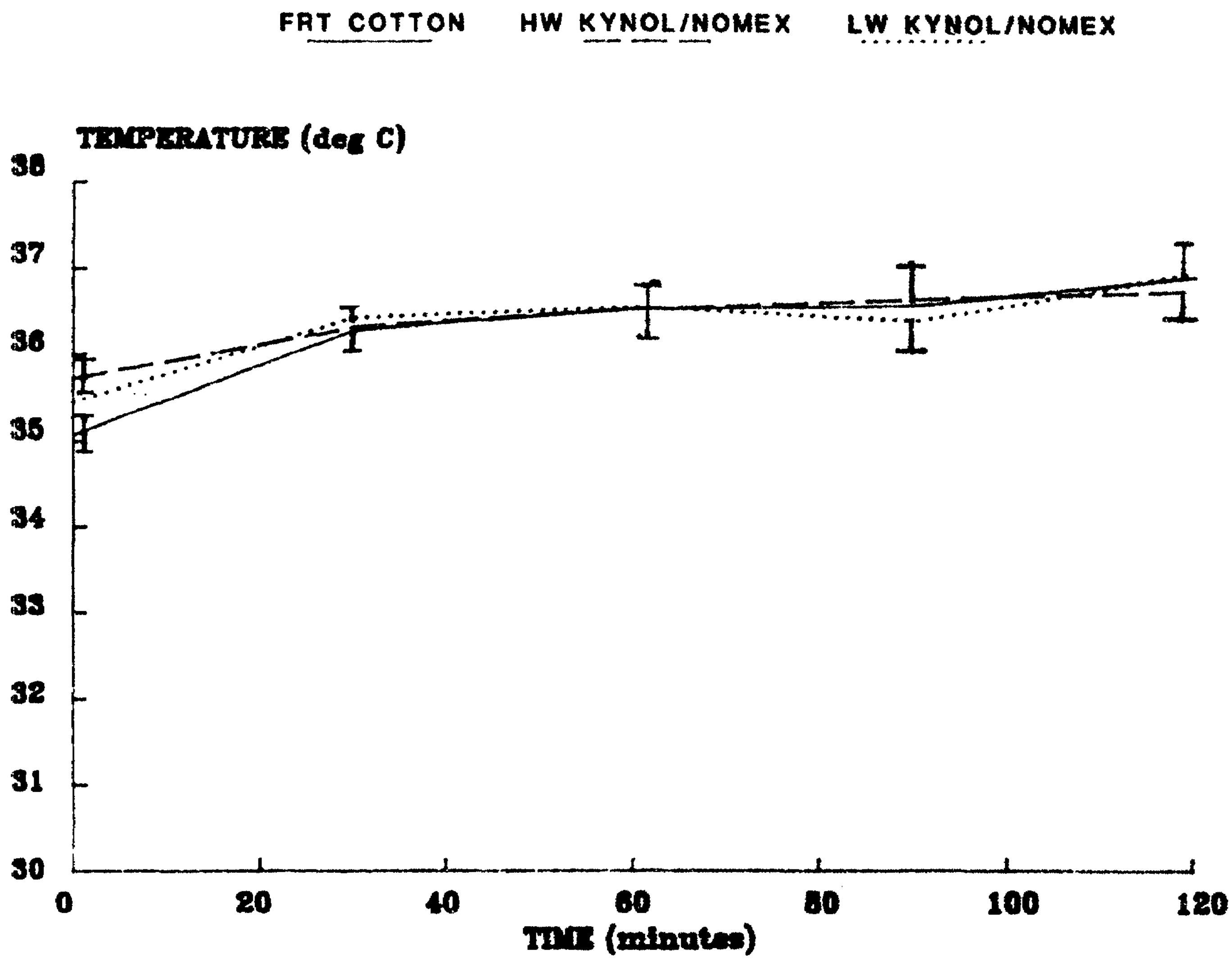


FIGURE 7

HEART RATE

21.1 deg C / 50% R.H.

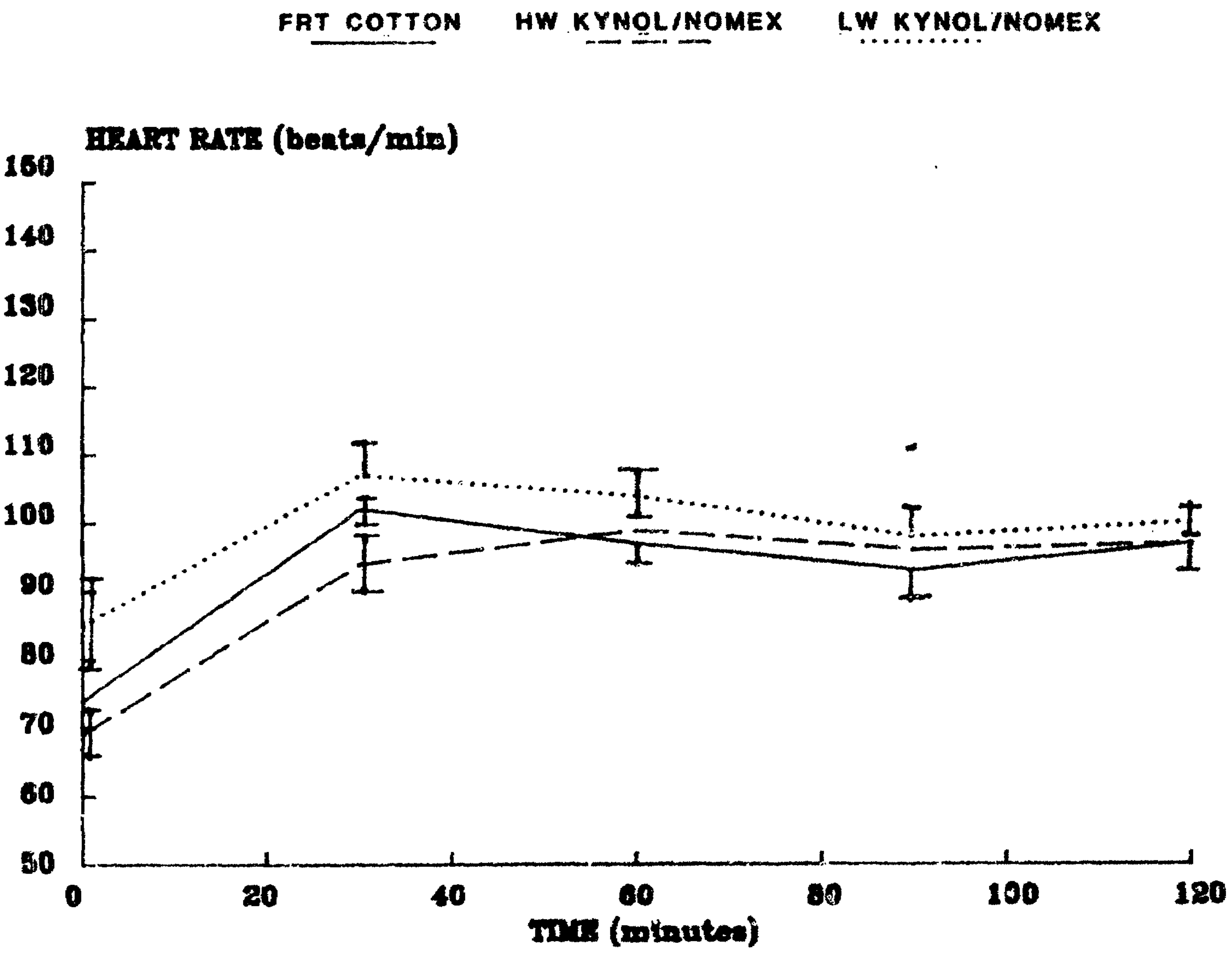


FIGURE 8
HEART RATE
35.0 deg C / 70% R.H.

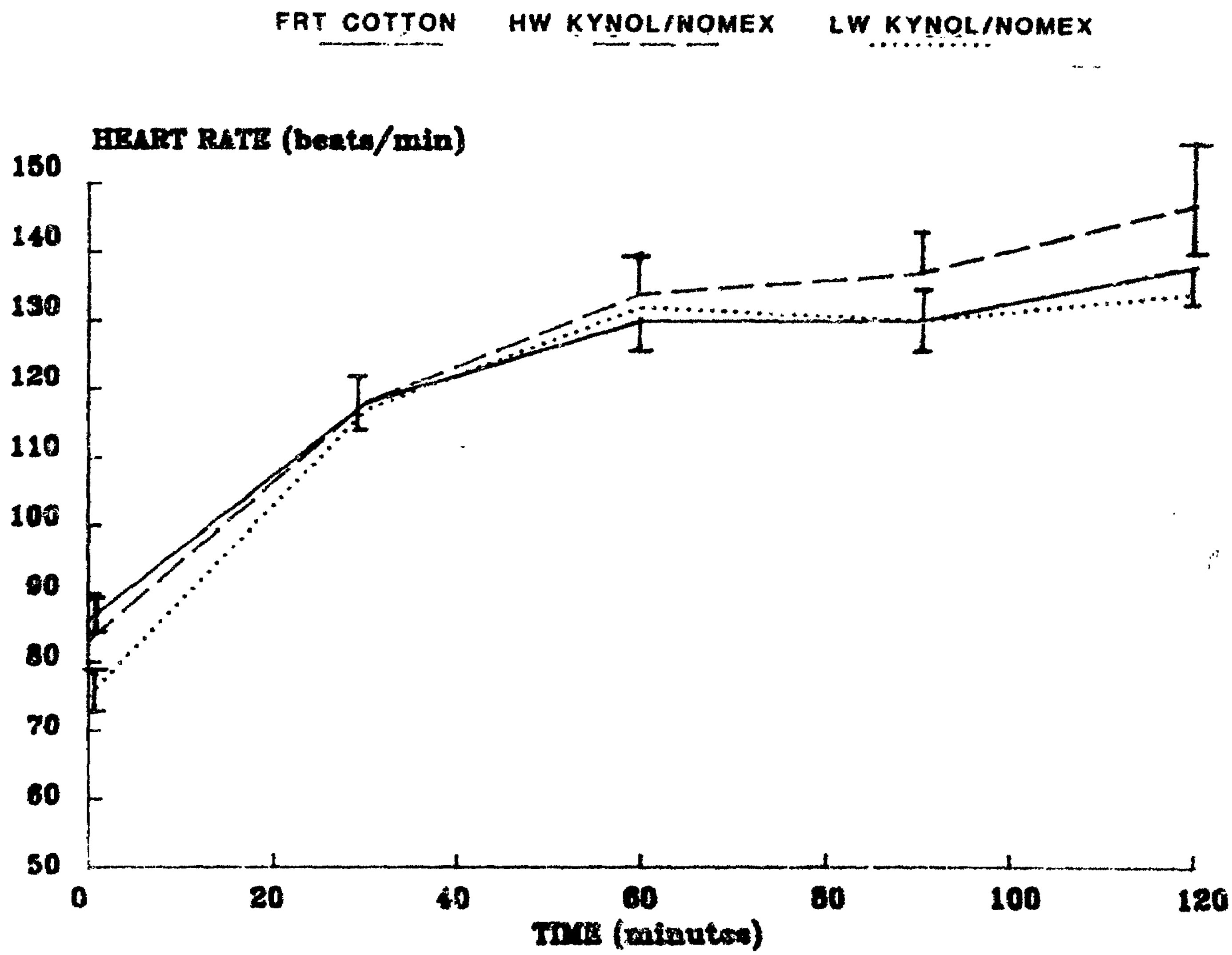


FIGURE 9

HEART RATE

48.9 deg C / 20% R.H.

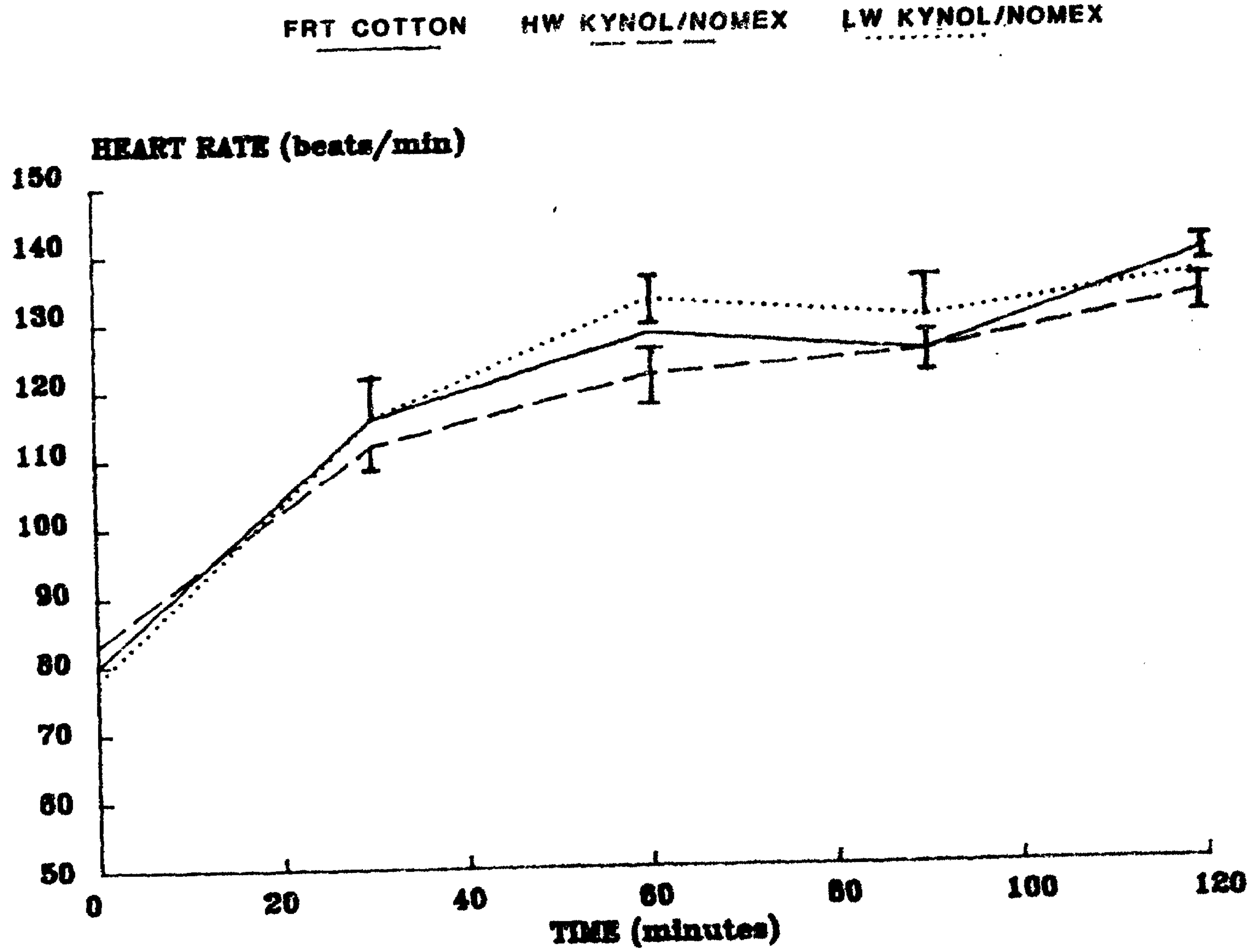
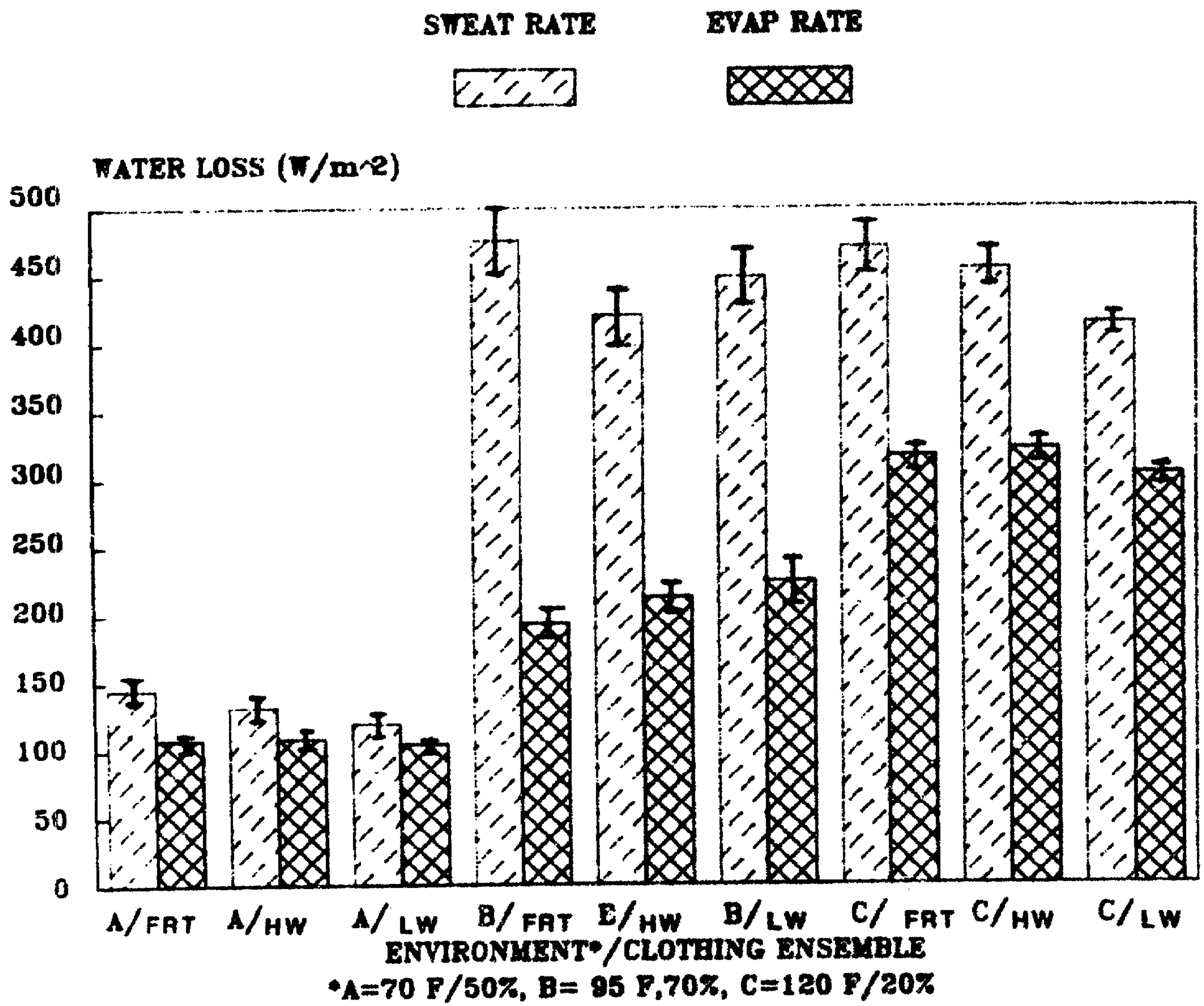


FIGURE 10
SWEAT AND EVAPORATION RATES



TAB D

HEAT PROTECTION

HEAT PROTECTION

INTRODUCTION

The flame resistance and heat protection characteristics of Kynol/Nomex blend materials were evaluated and compared to fire retardant treated (FRT) cotton materials previously judged suitable for use in a Navy fire retardant (FR) shipboard utility uniform. The materials evaluated are shown in Table I and their application in uniform components is also indicated. Tests were conducted on the materials alone and in a garmént configuration.

In studying the heat protection provided by these materials and uniforms the following information was determined:

a. Vertical flammability resistance of materials before and after laundering

b. Char through times at different radiant heat flux levels

c. Heat protection provided by the materials expressed as time to burn injury (second degree blister level burns) in:

(1) Radiant heat exposures

(2) Flame impingement exposures

d. Total heat protection provided by the materials in a uniform design (shirt/trouser) in a total fire envelopment situation (fire pit) for:

(1) 0% body area second degree blister level burn injury

(2) 20% body area second degree blister level burn injury

e. Heat protection provided by the materials in a uniform design (shirt/trouser) in a near proximity exposure to a $1500^{\circ}-2200^{\circ}F$ fuel fire at distances of 10 and 20 feet from the fire expressed as:

(1) Total heat protection at 0% body area second degree blister level burn injury

(2) Percent body area which sustained second degree blister level burn injury at a total heat of 10 g cal/cm^2

(3) Percent body area which sustained second degree blister level burn injury at 100 seconds

Table I
Materials Evaluated in Heat Protection Tests

Material	Weight (oz/yd^2)	Weave	Shade	Garment Use
70/30% Kynol/Nomex	4.5	Plain	Gold	Shirt
70/30% Kynol/Nomex	6.0	Plain	Gold	Shirt/Trouser
80/20% Kynol/Nomex	8.0	Twill	Gold	Trouser
100% FRT Cotton Chambray	6.5	Plain	Lt. Blue	Shirt
100% FRT Cotton Denim	12.0	Plain	Dark Blue	Trouser

VERTICAL FLAMMABILITY RESISTANCE OF MATERIALS BEFORE AND AFTER LAUNDERING

Procedure

In these experiments a 12 inch long by 2 3/4 inch wide strip of material was held vertically and exposed to a flame source at its bottom end for a time period of 12 seconds (Method 5903, Federal Test Method Standard 191). At the end of the exposure observations were made to determine after flame time and after glow time. The fabrics were then removed from the test assembly and the amount of material destroyed was measured and reported as char length. Five determinations were made for each material and the results averaged. The materials were tested new and after 15 simulated shipboard launderings using Standard Navy Wash Formula II.

Results

As can be seen in Table II all the materials showed excellent vertical flammability resistance both new and after 15 simulated shipboard launderings. Maximum average char lengths measured were 3.5 inches for the Kynol/Nomex materials and 3.3 inches for the FRT Cotton materials.

Table II Vertical Flammability Performance of Fabrics
Before and After Simulated Shipboard Launderings

Material	New After Flame (sec)	New After Glow (sec)	New Char Length (in)	15 Launderings After Flame (sec)	15 Launderings After Glow (sec)	15 Launderings Char Length (in)
70%/30% Kynol/Nomex 4.5 oz/yd^2	0	1	3.5	0	1	2.9
70%/30% Kynol/Nomex 6.0 oz/yd^2	0	1	3.5	0	1	2.3
80%/20% Kynol/Nomex 8.0 oz/yd^2	0	2	3.4	0	1	2.8
FRT 100% Cotton 6.5 oz/yd^2	0	1	3.2	0	1	3.3
FRT 100% Cotton 12.0 oz/yd^2	0	1	2.9	0	1	3.0

CHAR THROUGH TIMES OF MATERIALS EXPOSED TO DIFFERENT RADIANT HEAT FLUX LEVELS

Procedure

In this experiment the materials were subjected to radiant heat flux levels ranging from 0.3 to 1.0 gcal/cm^2/sec until failure occurred or for a maximum of 120 seconds. Five specimens of each material were evaluated and the results averaged.

A quartz lamp radiant heat apparatus was employed as the heat source. The flux levels were varied by changing the input voltage to the lamps with a variac. The flux levels incident on the sample front surface were calibrated using a Medtherm Corporation water cooled heat flux transducer. Two lamp assemblies were positioned at 45 degree angles to the plane of the sample on each side of the centerline of the front surface of the sample. The exposed sample area was 4 inches long and 2 inches wide. The sample was evaluated in a vertical position.

Char through was judged by applying a small amount of pressure at the center backside of the specimen with a pencil eraser for the entire test period. The time when the pencil eraser penetrated the fabric because of significant material strength loss was recorded as char through.

Results

Table III shows the char through times obtained with the various fabrics. At a flux of 0.3 g cal/cm^2/sec none of the fabrics showed char through after 120 seconds At 0.5 g cal/cm^2/sec the FRT cotton materials began to show char through. The longer char through time for the lighterweight cotton fabric versus the heavier cotton fabric (105 sec versus 45 sec) can be attributed to color. The lighter weight cotton was light blue versus dark blue for the heavier cotton fabric (Table I). The lighter colored fabric is a more effective reflector of the radiant heat than the dark colored fabric until the front surface of the material begins to char.

At 0.8 g cal/cm^2/sec the heavier Kynol/Nomex material showed char through at 110 seconds. The cotton fabrics at this flux showed significantly lower and similar char through times (21 and 19 seconds). At 1.0 g cal/cm^2/sec all fabrics showed char through below 120 seconds. The two higher Nomex blended Kynol fabrics showed greater char through times than the lower Nomex blended Kynol material. All the Kynol/Nomex fabrics showed significantly higher char through times than the cotton fabrics which behaved similarly.

The data indicates that the Kynol/Nomex fabrics have greater heat resistance to degradation than the cotton fabrics. Higher percentages of Nomex in the blended Kynol fabrics appeared to improve heat resistance. For the two Kynol/Nomex fabrics blended similarly, the heavier weight fabric took longer to char through.

Table III Char Through Times at Different Radiant Heat Flux Levels

Fabric	Weight (oz/yd^2)	Radiant Heat Flux (g cal/cm^2/sec)			
		0.3	0.5	0.8	1.0
70/30% Kynol/Nomex	4.5	NC	NC	NC	34
70/30% Kynol/Nomex	6.0	NC	NC	NC	38
80/20% Kynol/Nomex	8.0	NC	NC	110	29
FRT 100% Cotton	6.5	NC	105	21	10
FRT 100% Cotton	12.0	NC	45	19	11

NC = No char through up to 120 seconds

HEAT PROTECTION PROVIDED BY MATERIALS EXPRESSED AS TIME TO BURN INJURY (SECOND DEGREE BLISTER LEVEL BURNS)

Procedure

Laboratory bench tests were performed to determine the protection times provided by the materials for radiant and flame impingement exposures.

Radiant Heat Exposures

The apparatus employed was the same as used in the char through tests. The materials were exposed to three different calibrated radiant heat flux levels. The radiant flux levels chosen were equivalent to those measured in reference 1 upwind from the edge of a 20 foot diameter fuel fire at distances of 4 feet (0.5 g cal/cm^2/sec), 16 feet (0.3 g cal/cm^2/sec) and 36 feet (0.1 g cal/cm^2/sec).

A Medtherm Corporation water cooled heat flux transducer was located behind the fabric specimens to measure the heat transmitted through the fabrics. Data were obtained with the heat flux transducer directly against the fabric and at a distance of one-half inch behind the fabric. Data from five samples of each fabric were averaged and reported. A Hewlett-Packard Data Aquisition System was used to convert the measured heat flux transmitted through the fabric to burn time estimations using burn data developed by Stoll and Chianta, Naval Air Development Center (Fig. 2 and ref. 2).

Flame Impingement Exposures

The apparatus employed was similar in construction to that developed by Stoll and Chianta, Naval Air Development Center, and described in reference 3. The materials were exposed in a horizontal position using a propane gas fueled Meker burner as the heat source. The heat source was calibrated with a Hy Cal Engineering Co. water cooled heat flux transducer at a flux level of 2.0 g cal/cm^2/sec. This flux level is generally accepted as average for a large fuel fire. An Albany Internationl Research Corporation skin simulant sensor was located in direct contact with the rear of the fabric to measure the heat transmitted through the fabric. As in the radiant tests, time to burn injury (second degree blister level burns) was estimated from burn data developed by Stoll and Chianta (Fig. 2). The average results from three samples of each fabric were reported.

Results

Radiant Heat Exposures

Table IV shows the time to burn injury (TBI) data for the materials exposed to different radiant heat flux levels with the heat flux transducer in contact with the materials. At each flux level, the FRT cotton materials showed higher TBIs than any of the Kynol/Nomex fabrics. For the most part, the TBI values were directly related to the weight of the fabrics regardless of the material type (greater weight-higher TBI) except for the lightweight FRT cotton fabric, which showed better performance for its weight than the other materials. This was attributed to the color of this fabric which was lighter than the others and more efficient in reflecting the radiant heat.

The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton materials. Weight of the fabric was more a measure of protection time achieved than other material properties.

In comparing Table IV data to Table III (Char Through Times), it can be seen that burns would be sustained at comparable heat flux levels long before significant material damage would occur with the cotton materials negating any benefit derived from using the higher heat resistant Kynol/Nomex fabrics.

Table IV Estimated Time to Burn Injury (TBI) with the Heat Flux Sensor in Contact with the Materials

Heat Flux ($g\ cal/cm^2/sec$)	Material	Weight (oz/yd^2)	TBI (sec)
0.5	70/30% Kynol/Nomex	4.5	10
	70/30% Kynol/Nomex	6.0	10
	80/20% Kynol/Nomex	8.0	13
	FRT 100% Cotton Chambray	6.5	15
	FRT 100% Cotton Denim	12.0	20
0.3	70/30% Kynol/Nomex	4.5	17
	70/30% Kynol/Nomex	6.0	18
	80/20% Kynol/Nomex	8.0	20
	FRT 100% Cotton Chambray	6.5	25
	FRT 100% Cotton Denim	12.0	33
0.1	70/30% Kynol/Nomex	4.5	67
	70/30% Kynol/Nomex	6.0	70
	80/20% Kynol/Nomex	8.0	72
	FRT 100% Cotton Chambray	6.5	78
	FRT 100% Cotton Denim	12.0	100

Table V shows the data for exposures to different radiant heat flux levels with the heat flux transducer one-half inch away from the materials. The characteristics of the data were similar to the contact case (Table IV) in that the heavier the material the greater the TBI except there were no exceptions to this relationship in these tests. With the sensor not in contact with the fabric, the TBIs for any particular fabric and test condition were at least twice as long with respect to the fabric contact case. As indicated for the contact case the Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton fabrics. The weight of the material was more indicative of potential protection time than any other material property for either material type.

As in the contact case burns would have occurred with the Kynol/Nomex fabrics long before any significant fabric damage (char through) would have happened (Table III) with the cotton fabrics negating to some degree the benefit of using the higher heat resistant Kynol/Nomex fabrics. For the 0.5 g cal/cm^2/sec flux level the heavier cotton fabric had a TBI essentially equivalent to its char through time at this flux (43 versus 45 sec.).

Table V Estimated Time to Burn Injury (TBI) with the Heat Flux Transducer 1/2 Inch in Back of the Materials

Heat Flux (g cal/cm^2/sec)	Material	Weight (oz/yd^2)	TBI (sec)
0.5	70/30% Kynol/Nomex	4.5	21
	70/30% Kynol/Nomex	6.0	27
	80/20% Kynol/Nomex	8.0	33
	FRT 100% Cotton Chambray	6.5	30
	FRT 100% Cotton Denim	12.0	43
0.3	70/30% Kynol/Nomex	4.5	42
	70/30% Kynol/Nomex	6.0	53
	80/20% Kynol/Nomex	8.0	63
	FRT 100% Cotton Chambray	6.5	60
	FRT 100% Cotton Denim	12.0	87
0.1	70/30% Kynol/Nomex	4.5	>100
	70/30% Kynol/Nomex	6.0	>100
	80/20% Kynol/Nomex	8.0	>100
	FRT 100% Cotton Chambray	6.5	>100
	FRT 100% Cotton Denim	12.0	>100

Flame Impingement Exposures

Table VI shows the estimated time to burn injury (TBI) when the materials were subjected to a direct flame exposure at a heat flux level of 2.0 g cal/cm^2/sec with the skin sensor in contact with the materials. As can be seen the time to burn injury can be correlated to the weight of the fabrics rather than the fiber content of the materials. Considering the Kynol/Nomex fabrics the lighter 4.5 oz/yd^2 fabric had a 2.2 second TBI while the heavier 8.0 oz/yd^2 fabric had a 4.3 sec TBI. For the FRT cotton fabrics, the lighter 6.5 oz/yd^2 fabric had a TBI of 3.9 seconds and the heavier 12 oz/yd^2 had a TBI of 6.4 seconds. As indicated in the radiant heat tests the Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton fabrics. The weight of the materials was more indicative of potential protection time than any other material property for either material type.

Table VI Estimated Time to Burn Injury (TBI)
Flame Impingement - Heat Flux 2.0 g cal/cm^2/sec

Material	Weight (oz/yd^2)	TBI (Sec)
70/30% Kynol/Nomex	4.5	2.2
70/30% Kynol/Nomex	6.0	3.0
80/20% Kynol/Nomex	8.0	4.3
FRT 100% Cotton Chambray	6.5	3.9
FRT 100% Cotton Denim	12.0	6.4

Flame Envelopment Tests

Fire pit tests were conducted at the Naval Air Development Center (NADC), Warminster, PA to determine the degree of fire protection provided by the Kynol/Nomex and FRT cotton materials in a utility uniform configuration identical in design to the Navy's standard utility uniform.

In these tests three Kynol/Nomex blend fabrics in two uniform combinations consisting of a shirt and trouser, and one 100% FRT cotton two piece uniform consisting of a chambray shirt and a denim trouser were evaluated. The weights and construction of the fabrics used in these uniforms are shown in Table XII. The fire exposure time was two seconds, which was based on the Navy Decision Coordinating Paper (NDCP) No. S-1121-OL, April 29, 1980 protection requirement for shipboard utility uniforms.

Table VII - Characteristics of FR Utility Uniforms

Component	Material	Construction	Weight (oz/yd^2)
FRT Cotton			
Shirt	100% FRT Cotton	Chambray	6.5
Trouser	100% FRT Cotton	Denim	12.0
Lightweight Kynol/Nomex			
Shirt	70/30% Kynol/Nomex	Plain Weave	4.5
Trouser	70/30% Kynol/Nomex	Plain Weave	6.0
Heavyweight Kynol/Nomex			
Shirt	70/30% Kynol/Nomex	Plain Weave	6.0
Trouser	80/20% Kynol/Nomex	Twill	8.0

Equipment

Fire Pit Facility

The fuel fire pit facility employs a rotary crane to carry a dressed manikin through the flames. The rotation of the crane was adjusted so that the manikin was engulfed in the flames for two seconds.

The fire pit consists of a pool of water contained within a 30 feet long by 20 feet wide concrete barrier about eight inches deep. A grid of aluminum angle stock divides the surface of the water into 20 cells. Each cell contains a fuel nozzle. Just before each test, fuel is pumped into the pool through the nozzles and allowed to rise to the top of the water and spreads along the surface to give a fairly even distribution. Four propane burners are arranged around the edge of the pit to ignite the fuel. The fuel used in these tests was JP-5.

The fire pit area is surrounded on three sides by a 12 foot fence about 20 feet away from the pit on each side. On the fourth side is a concrete block wall 10 feet high behind which the control area is located. In operation, the pit is fueled, ignited, and the fire allowed to fully develop over a 15-20 second period at which time the crane with the manikin attached to a crane carry frame is started from a point behind the wall. After passing through the flames, the manikin completes its rotation by finishing behind the wall. The wall acts as a shutter to limit manikin heat exposure to the period in which it is engulfed by flames. Mounted to the crane manikin carry frame is a HyCal Engineering Corporation water cooled heat flux transducer to measure the heat load of the fire.

Test Manikins

Fiberglass manikins coated with a fire retardant paint were employed in these tests. The manikins were equipped with leather patches at 26 discrete body sites in the torso, leg, and arm areas (Fig. 1 and Table VIII). Affixed to each leather patch was a set of seven temperature sensitive tapes each measuring approximately 5/16 x 1-7/8 inches. Each tape was stamped with its activation temperature value. When a tape reaches its activation temperature it changes shade permanently from grey to black. The activation temperature of each set ranged from 220° to 280°F in increments of 10°F. The response of the tape and leather patch assemblies had been precalibrated to equate to burn injury levels established by Stoll and Chianta in ref. 2 (Fig. 2).

To calibrate the tape leather patch assemblies to the Stoll-Chianta burn injury curves, the quartz lamp radiant heat tester used in the char through and radiant heat tests was employed. A Medtherm water cooled heat flux transducer was initially placed behind a single layer of fabric and the radiant heat load incident on the fabric was increased in discrete increments for exposures of two seconds until the heat flux measurements behind the test fabric were equivalent to the pain, survival, and blister levels shown in Fig. 2 for a two second exposure. The heat flux transducer was then replaced by the tape-leather patch assemblies. Employing the same radiant heat loads, and 2 second exposures used to determine pain to blister levels with the heat flux transducer, the highest tape activation temperature for each of these conditions was noted and is shown in Table IX. The percentage of body burn was estimated for those tapes that activated at 280°F (second degree blister level burn).

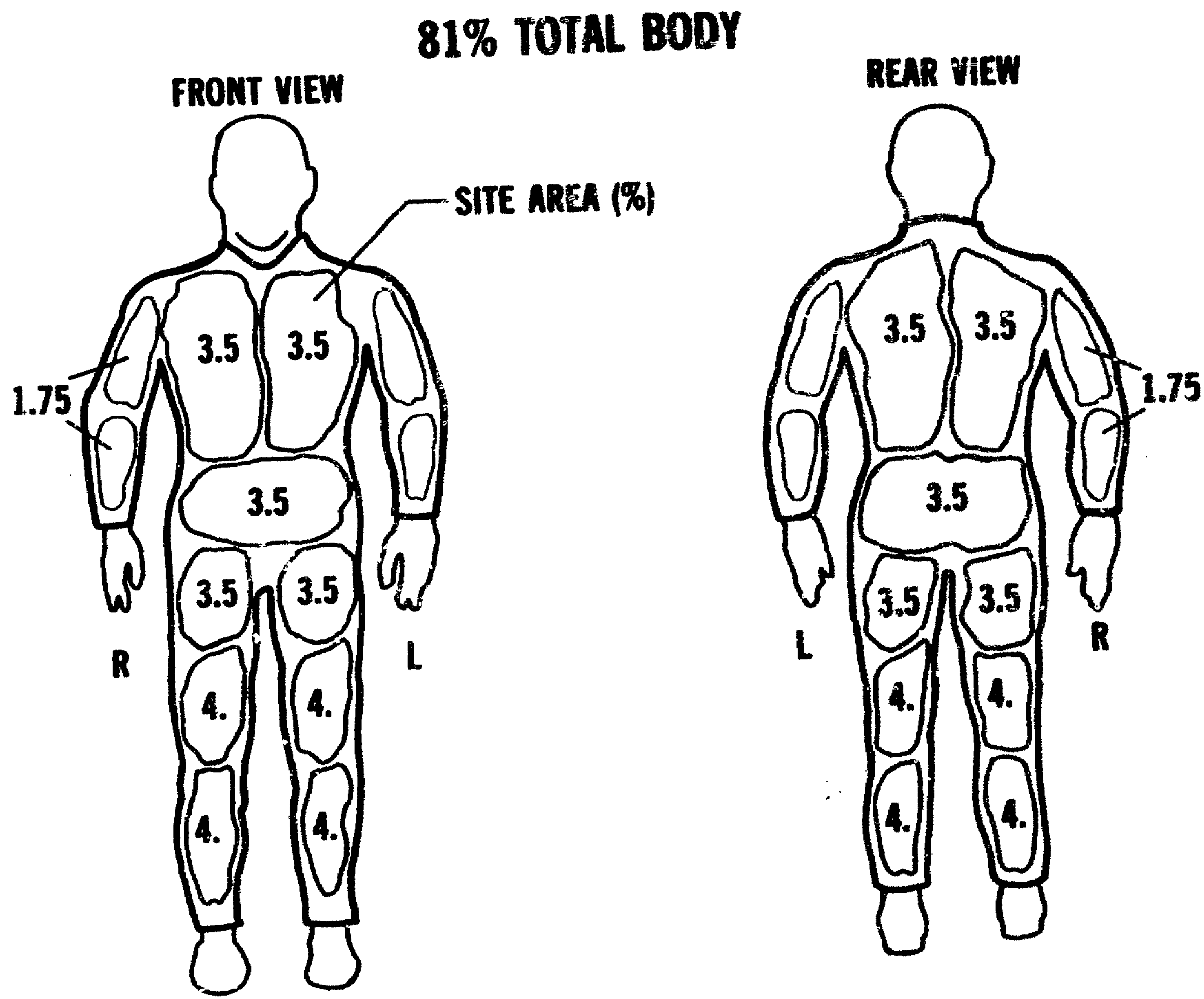


FIGURE 1. MANIKIN PAPER TAPE TEMPERATURE SENSOR SITES

Table VIII - Sensor Sites

1. UT2F Upper Torso 2 Front
2. UT2B Upper Torso 2 Back
3. UT3F Upper Torso 3 Front
4. UT3B Upper Torso 3 Back
5. UT6F Upper Torso 6 Front
6. UT6B Upper Torso 6 Back
7. LT1F Lower Torso 1 Front
8. LT1B Lower Torso 1 Back
9. LT2F Lower Torso 2 Front
10. LT2B Lower Torso 2 Back
11. RA3FU Right Arm 2 Front UP
12. RA2FD Right Arm 2 Front Down
13. RA2BU Right Arm 2 Back Up
14. RA2BD Right Arm 2 Back Down
15. LA2FU Left Arm 2 Front Up
16. LA2FD Left Arm 2 Front Down
17. LA2BU Left Arm 2 Back Up
18. LA2BD Left Arm 2 Back Down
19. RL1F Right Leg 1 Front
20. RL1B Right Leg 1 Back
21. RL3F Right Leg 3 Front
22. RL3B Right Leg 3 Back
23. LL1F Left Leg 1 Front
24. LL1B Left Leg 1 Back
25. LL3F Left Leg 3 Front
26. LL3B Left Leg 3 Back

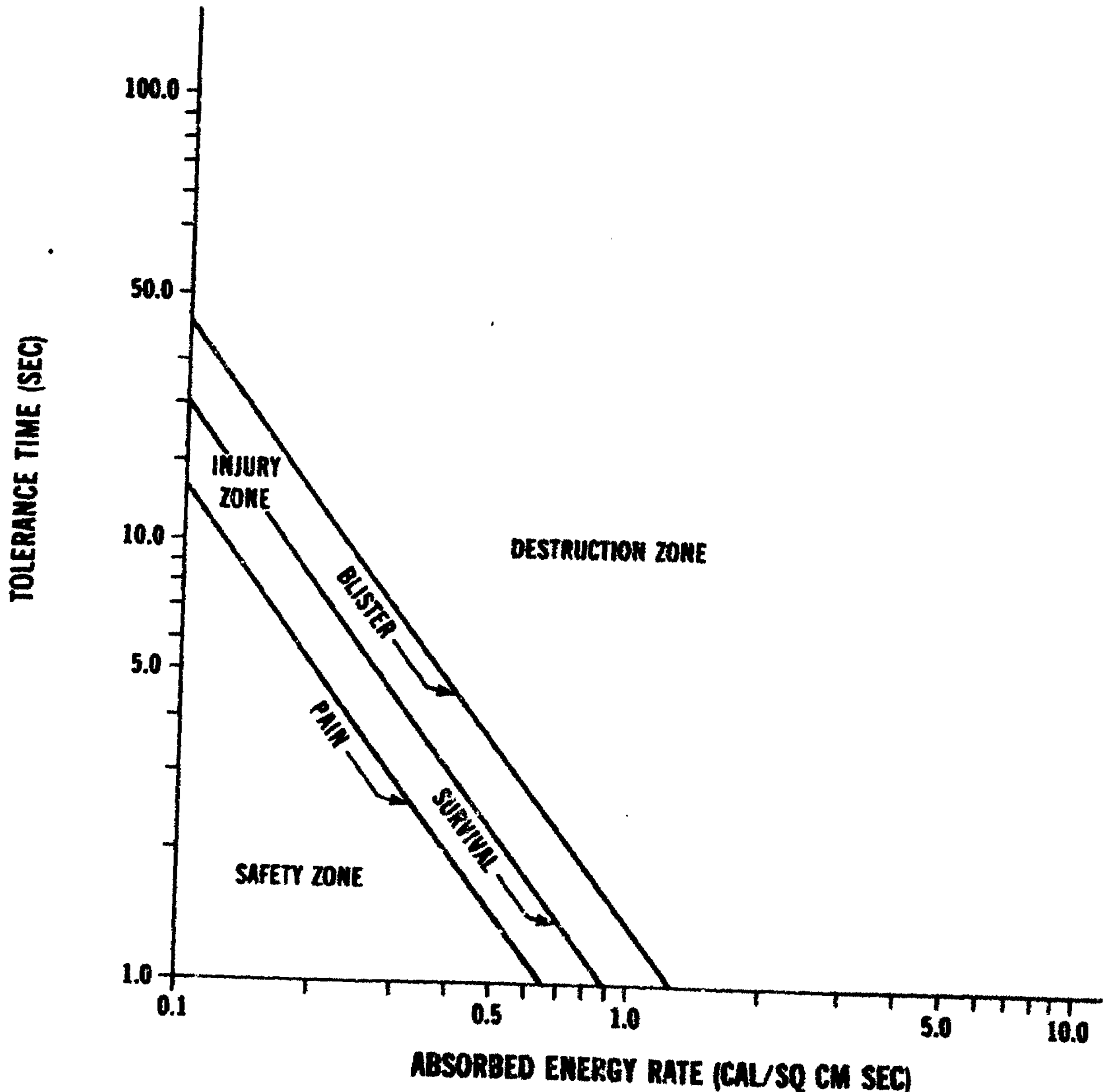
Table IX - Relationship of Burn Level to Paper Tape Activation Temperature

Degree of Burn Injury	Paper Tape Temp (^{o}F)*
Pain	240
Survival	260
Blister	280

* Body burn was calculated for a tape activation temperature of 280^{o}F.

FIGURE 4

EVALUATION OF THERMAL PROTECTION STOLL AND CHIANTA



HUMAN SKIN TOLERANCE TIME TO ABSORBED THERMAL ENERGY DELIVERED IN A RECTANGULAR HEAT PULSE.

Procedure

The test manikins instrumented with the paper tape-leather patch assemblies were dressed with underwear consisting of a t-shirt and boxer shorts, calf length wool blend socks, chukka boots, and the particular test garment employed. The dressed manikin was then mounted to the crane manikin carry frame and isolated from the fuel pit behind the cement block wall.

Water and then JP-5 fuel were introduced into the pit and ignited and allowed to preburn until the fire was fully developed. The crane was then energized and the manikin directed through the fire and then de-energized when the manikin appeared behind the cement block wall. During the period of exposure the output of the heat flux transducer attached to the manikin carry frame was measured with a millivolt recorder. Movie cameras were placed to monitor the manikin emerging from the flames so that the time of any after flame condition could be determined.

After completion of a series of tests the manikins were undressed and the temperatures of the activated tapes were noted at each location on the manikin surface and total heat exposure of the manikin for each test was determined by integrating the heat flux transducer output. The activation temperature of the tapes was then translated to percent burn injury area for each exposure and related to the total heat of exposure obtained from the heat flux data.

Test garments were evaluated both in a new condition and after being subjected to 15 simulated shipboard launderings using Navy Shipboard Wash Formula II. The number of tests conducted on each of the test garments in both the new and laundered state are shown in Table X.

Because of the variation in the heat exposure and burn injury measurements between tests on each garment, a linear regression analysis was performed on the test data to establish the relationship between total heat of exposure and extent of burn injury for each type of test garment.

Table X Number of Test Garments of Each Type Evaluated in a New and Laundered Condition

Test Garments	Condition	Number Tested
FRT Cotton	New	10
	Laundered	10
Lightweight Kynol/Nomex	New	10
	Laundered	10
Heavyweight Kynol/Nomex	New	10
	Laundered	10

Results

FRT 100% Cotton Uniform (Table XI)

New Condition - Total heat from the 10 exposures conducted ranged from 2.4 to 9.7 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 14 percent. The average total heat was 5.4 $\pm$ 2.4 $gcal/cm^2$ and the average estimated burn injury area was 5 $\pm$ 4 percent.

Laundered - Total heat from the 10 exposures conducted ranged from 2.4 to 9.6 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 9 percent. The average total heat was 5.1 $\pm$ 2.3 $gcal/cm^2$ and the average estimated burn injury area was 3 $\pm$ 3 percent.

Lightweight Kynol/Nomex Uniform (Table XI)

New Condition - Total heat from the 10 exposures conducted ranged from 1.4 to 8.6 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 22 percent. The average total heat was 4.8 $\pm$ 2.3 $gcal/cm^2$ and the average estimated burn injury area was 9 $\pm$ 8 percent

Laundered - Total heat from the 10 exposures conducted ranged from 1.3 to 8.5 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 22 percent. The average total heat was 5.0 $\pm$ 2.2 $gcal/cm^2$ and the average estimated burn injury area was 7 $\pm$ 6 percent.

Heavyweight Kynol/Nomex Uniform (Table XI)

New Condition - Total heat from the 10 exposures conducted ranged from 2.4 to 7.6 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 9 percent. The average total heat was 5.0 $\pm$ 1.7 $gcal/cm^2$ and the average estimated burn injury area was 4 $\pm$ 4 percent.

Laundered - Total heat from the 10 exposures conducted ranged from 2.4 to 7.6 $gcal/cm^2$ and burn injury area estimates ranged from 0 to 13 percent. The average total heat was 5.0 $\pm$ 1.7 $gcal/cm^2$ and the average estimated burn injury area was 4 $\pm$ 4 percent.

Table XI - Individual Total Heat - Estimated Blister Level Burn Injury Data for 2 Second - JP 5 Fuel Tests

Condition	FRT Cotton Total Heat (gcal/cm^2)	FRT Cotton Body Burn (%)	Lightweight Kynol/Nomex Total Heat (gcal/cm^2)	Lightweight Kynol/Nomex Body Burn (%)	Heavyweight Kynol/Nomex Total Heat (gcal/cm^2)	Heavyweight Kynol/Nomex Body Burn (%)
New	2.4	0	1.4	0	2.4	0
	4.3	0	2.0	0	3.2	0
	3.0	2	5.3	4	4.8	0
	5.6	2	5.7	4	5.6	0
	2.0	4	3.6	4	3.2	2
	5.0	5	6.0	7	4.8	4
	7.6	5	2.6	10	6.6	4
	7.5	6	5.4	17	4.5	8
	7.1	9	7.6	19	7.6	8
	9.7	14	8.6	22	7.5	9
Average	5.4	5	4.8	9	5.0	4
	± 2.4*	± 4	± 2.3	± 8	± 1.7	± 4
15 Shipboard Launderings	2.4	0	1.3	0	2.4	0
	4.3	0	2.0	0	3.2	0
	7.4	0	5.3	4	4.8	0
	2.9	2	5.7	4	5.5	0
	5.6	2	7.5	4	3.2	2
	5.0	4	6.0	4	4.7	4
	1.9	4	5.9	7	6.5	4
	4.9	5	2.6	9	5.0	8
	7.0	5	5.3	13	7.6	8
	9.6	9	8.5	22	7.5	13
Average	5.1	3	5.0	7	5.0	4
	± 2.3	± 3	± 2.2	± 6	± 1.7	± 4

* Denotes standard deviation

Comparison of Test Garment Results

Linear regression curves (Fig. 3) for the new garments and for laundered garments (Fig. 4) show the extent of estimated burn injury as a function of total heat of exposure. It is quite clear from Fig. 3 that the heavier uniforms (FRT cotton and HW Kynol/Nomex) when new provided significantly more heat protection than the LW Kynol/Nomex uniform, and the protection provided by the FRT cotton and HW Kynol/Nomex uniforms was similar. Fig. 4 indicates there was some protection degradation for the HW Kynol/Nomex uniform after laundering. The LW Kynol/Nomex and cotton uniforms showed improved protection after laundering. These changes after laundering were probably more related to test variability than the condition of the garments. As in the bench tests, the Kynol/Nomex uniforms showed no unique burn protection characteristics with respect to the FRT cotton uniforms, results being more associated with the weight of the garments rather than any other material property. The correlation coefficients for the curves in Fig. 3 related to a confidence level of greater than 95% For the Fig. 4 curves the confidence level was at least 90%.

Significance of Burn Injury

According to the Standard First Aid Training Course Manual NAVEDTRA 10081-N (Ref 4), burns involving more than 20 percent of the skin surface area endanger life and 30 percent burns are usually fatal if adequate medical treatment is not received. The U.S. Army and Air Force when estimating the total heat protection provided by a particular uniform for tank and air crews use 20 percent body burn area as the cutoff criteria. Using this 20 percent criteria one can estimate the total heat protection provided by a garment at a level that would not endanger life. Considering this criteria and using the linear regression curves in Fig. 3 the LW Kynol/Nomex uniform new would require a total heat exposure of 8.8 g cal/cm^2 for a 20% body area blister level burn to occur. The burn area for the HW Kynol/Nomex and the FRT Cotton uniforms new was well below the 20% body burn cutoff criteria in all tests. For a total heat of 8.8 g cal/cm^2 the estimated body area blister level burns were 8.5% and 9.3% for the HW Kynol/Nomex and FRT cotton uniforms, respectively.

As shown in Fig 4, once laundered the burn area for the LW Kynol/Nomex uniform fell below the 20% body burn area cutoff criteria with an estimated body burn area of 13.5 percent at a total heat of 10.0 g cal/cm^2. The burn area for the laundered HW Kynol/Nomex and FRT cotton uniforms at the 10.0 g cal/cm^2 total heat level was 12% and 6%, respectively.

The estimated total heat protection provided before any second degree level burn is reached can be estimated from the linear regression curves (Fig 3 & 4). Considering new garments a total heat exposure of 1.6 g cal/cm^2 for the LW Kynol/Nomex uniform, 2.2 g cal/cm^2 for the FRT Cotton uniform, and 2.5 g cal/cm^2 for the HW Kynol/Nomex uniform would be required before a second degree burn would be sustained. After laundering these estimates were 1.0 g cal/cm^2 for the LW Kynol/Nomex and FRT Cotton uniforms, and 3.0 g cal/cm^2 for the HW Kynol/Nomex uniform.

FIGURE 3

PERCENT BODY BURN VS TOTAL HEAT (CAL./SQ. CM)

FLAME ENVELOPMENT - NEW GARMENTS

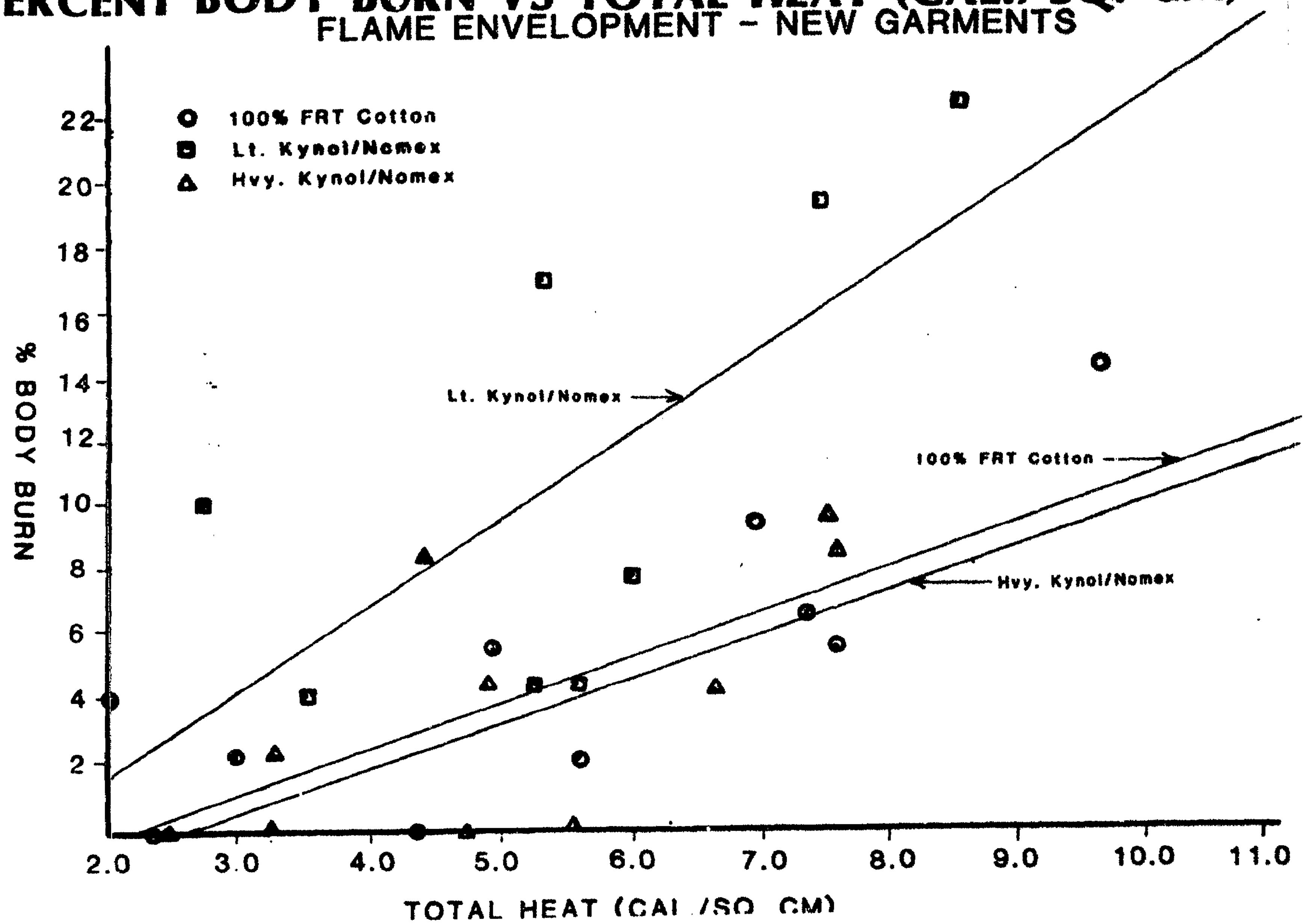
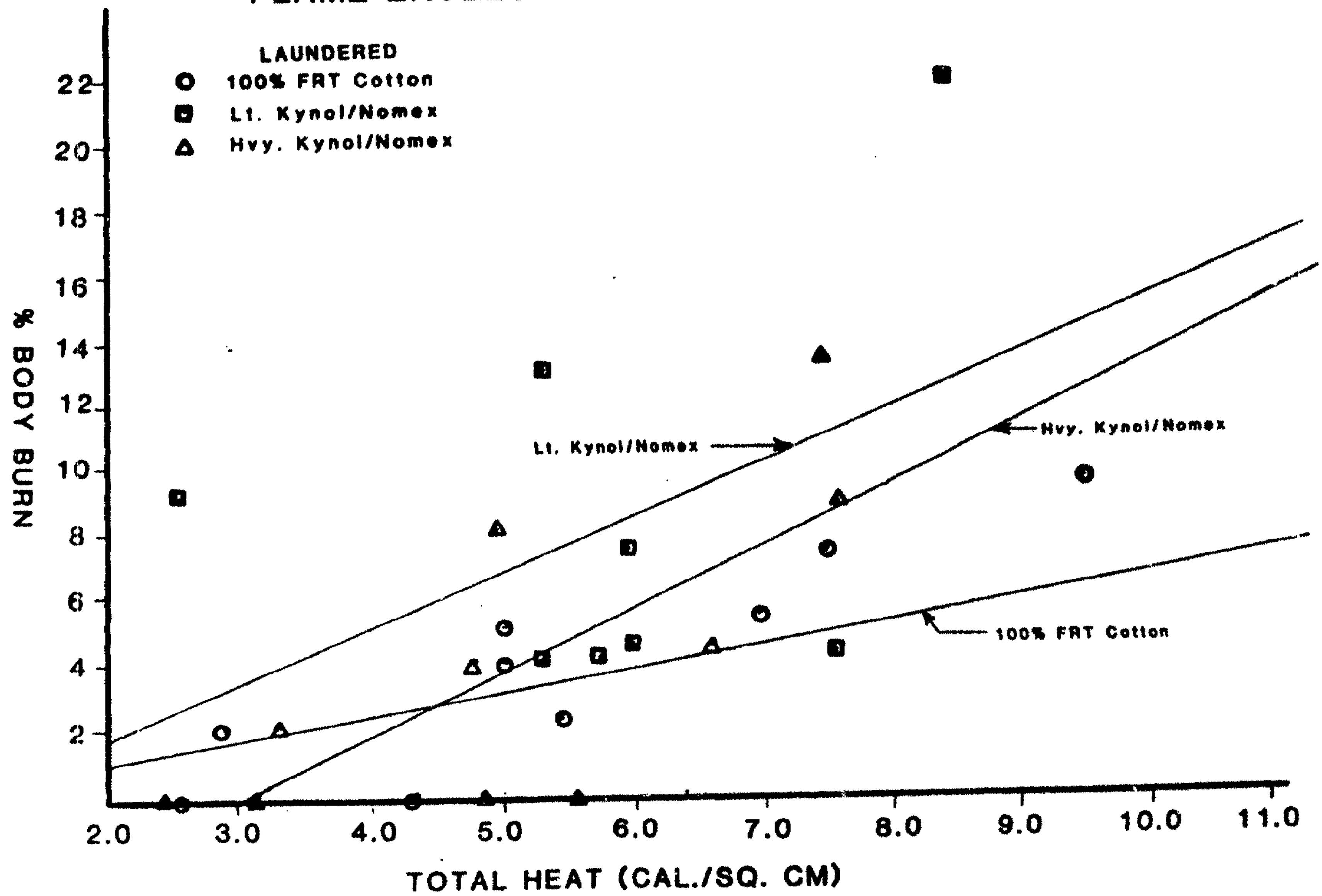


FIGURE 4

PERCENT BODY BURN VS TOTAL HEAT (CAL./SQ. CM)

FLAME ENVELOPMENT – LAUNDERED GARMENTS



Discussion

In these flame envelopment studies the FRT cotton uniform and the HW Kynol/Nomex uniform, in a new condition, were equivalent in protection and significantly more protective than the LW Kynol/Nomex uniform. Differences in performance between the new and laundered conditions for the different type uniforms were believed to be more related to the variability associated with these types of tests than any changes in the materials as a result of laundering.

FIRE EXPOSURE PROTECTION IN CLOSE PROXIMITY TO THE FIRE PIT

The fire proximity exposure tests were conducted simultaneously with the fire entry tests with an instrumented manikin dressed in the test clothing placed at distances of 10 and 20 feet from the fire. Data relating the burn injury protection of each of the uniforms to this exposure were established.

Equipment

Data Acquisition System

The instrumentation was comprised of a Hewlett Packard Model 165200 series computer, model 3495A scanner and model 3456A Digital Voltmeter. The computer is based on the Motorola MC 68000 16 bit microprocessor with a 32 bit internal architecture. The voltmeter is capable of up to 330 readings per second with 100 nanovolt resolution capability and fast AC voltage reading ratio. The system uses HPIB/IEEE 488 interfacing techniques for communication between the Computer, Scanner, and Digital Voltmeter.

The computer was subsequently programmed to convert the heat flux transducer data obtained in this study to TBI values using the Stoll and Chianta burn data shown in Fig. 2.

Instrumented Manikin

A fiberglass manikin instrumented with twenty heat flux transducers was used to determine the resulting burn injury as might occur in a human configuration. The transducers, had a heat flux range of .05 to .55 g cal/cm^2/sec with a response time of less than 1500 milliseconds.

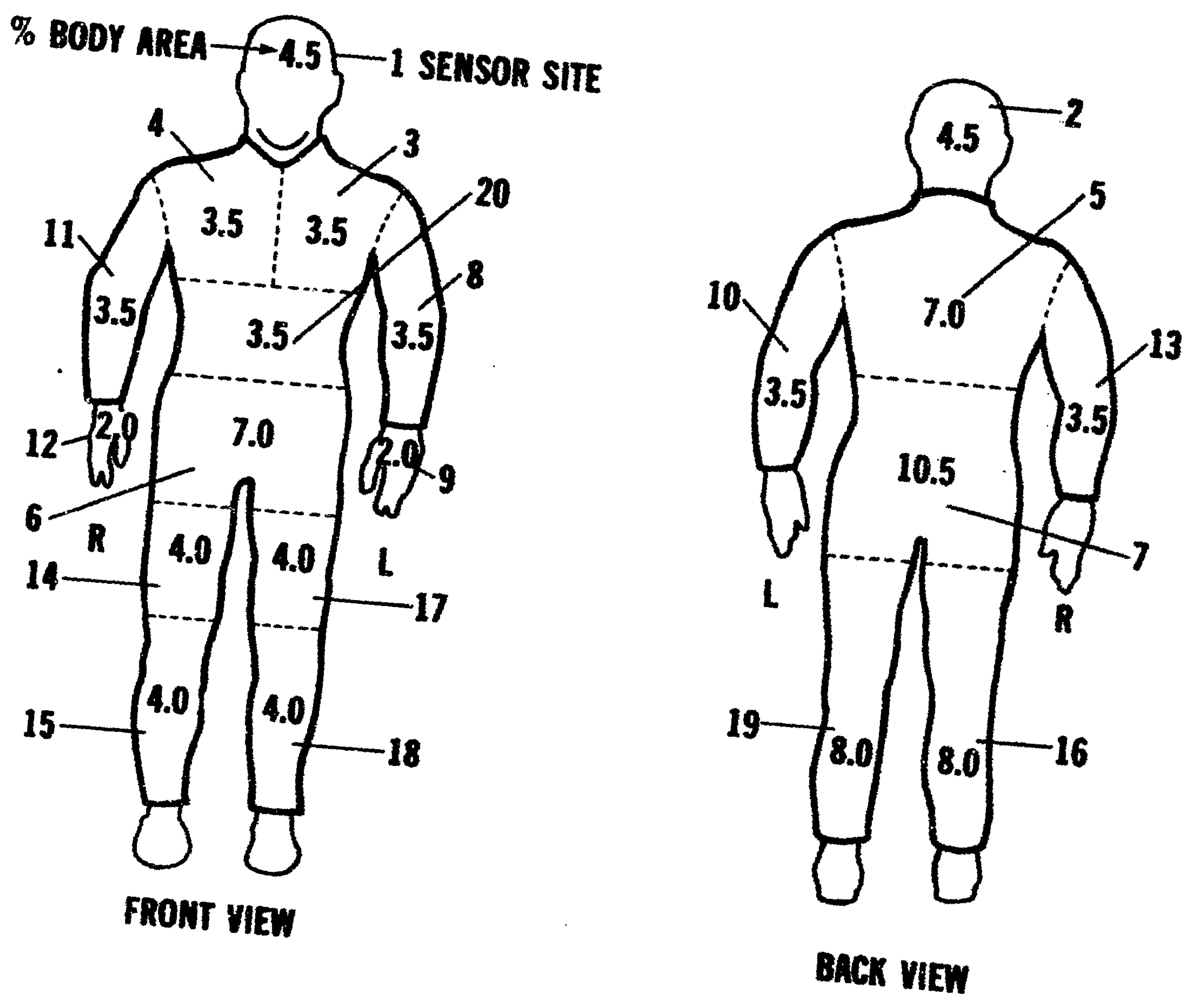
Although the manikin contained 20 sensors, only those covered by the test uniform were used to calculate the percent body burn area. This area represented 81% of the total body area and involved 16 of the 20 heat flux transducers. The hands, head, and feet were omitted from the total calculation.

Table XIII lists the location and percent body area represented by each sensor. Figure 5 illustrates the percent body area covered by each.

Table XIII
Manikin Sensor Sites

Sensor	Location	% Body Area
1	Forehead	Not Included
2	Back of Head	Not Included
3	Left Breast	3.5
4	Right Breast	3.5
5	Middle Back	7.0
6	Front Groin	7.0
7	Lower Back	10.5
8	Front Lower Arm Left	3.5
9	Left Hand	Not Included
10	Back Upper Arm Left	3.5
11	Front Lower Arm Right	3.5
12	Right Hand	Not Included
13	Back Upper Arm Right	3.5
14	Right Leg Front Thigh	4.0
15	Right Leg Shin	4.0
16	Right Leg Calf	8.0
17	Left Leg Front Thigh	4.0
18	Left Leg Shin	4.0
19	Left Leg Calf	8.0
20	Stomach	3.5
	Total	81.0

Figure 5.
INSTRUMENTED MANIKIN



In addition to the 20 heat flux transducers incorporated in the fiberglass manikin, a total heat flux transducer and radiometer were mounted at waist level on a frame used to support the manikin to record both the incident radiant and total heat of the fire on the dressed manikin surface.

Procedure

The burn injury data obtained with the instrumented manikin at ten and twenty feet were analyzed in the following way. At a total exposure time of 100 seconds the percent body burn was calculated. Initially the heat flux data obtained by each of the heat flux transducers was recorded. This heat flux data was then converted to a total heat value (cal/cm^2) for the 100 second duration. This information was then compared to burn injury data plotted on a time versus total energy basis for a second degree blister level burn using the burn data developed by Stoll and Chianta (Fig. 2). As previously noted the head, hands, and feet of the manikin, a total of 19% of the body area, were not covered by the test uniform and were not included in calculating the percent body burn for each of the test uniforms.

The characteristics of the uniforms tested are shown in Table XIV. Each uniform was exposed to several test fires at distances of 10 and 20 feet from the fire. However, because of the low levels of incident heat produced by some of the fires, only five test runs representing the worst burn conditions for each uniform were selected for data analysis.

Table XIV Test Uniforms

Uniform	Shirt	Trouser
Lightweight Kynol/Nomex	4.5 oz/yd^2 70/30% Kynol/Nomex	6.0 oz/yd^2 70/30% Kynol/Nomex
Heavyweight Kynol/Nomex	6.0 oz/yd^2 70/30% Kynol/Nomex	8.0 oz/yd^2 80/20% Kynol/Nomex
FRT Cotton	6.5 oz/yd^2 100% FRT Cotton	12 oz/yd^2 100% FRT Cotton

Results

Lightweight Kynol/Nomex Uniform

Five test runs were analyzed with the manikin at a distance of ten feet from the fire. Table XV illustrates the total and radiant heat loads generated by each fire after 100 seconds and the percent body burn area sustained. The average total heat of the fires was 11.9 g cal/cm^2, with 9.2 g cal/cm^2 attributed to radiant heat. Based on the average heat exposure burn injury occurred over 9% of the covered body area. Among the five test runs conducted the highest total heat level recorded was 25.5 g cal/cm^2 (19.4 g cal/cm^2 radiant). At this level the body burn area was 29%, 21% on the upper body and 8% on the lower body.

Table XV Heat Load and Burn Data
for Lightweight Kynol/Nomex Uniform
at 10 Feet From Fire After 100 Seconds Exposure

Total Heat (g cal/cm^2)	Radiant Heat (g cal/cm^2)	Body Burn (%)
25.5	19.4	29
9.1	7.1	4
8.6	6.8	0
8.5	6.7	8
8.2	6.3	4
11.9 ± 6.8*	9.2 ± 5.1	9 ± 10.3

*Denotes standard deviation.

Five test runs were also conducted with the manikin at a distance of 20 feet from the fire. Table XVI lists the total and radiant heat loads generated by each fire and the percent body burn area suffered. The average total heat of the fires recorded at this distance was 7.0 g cal/cm^2, 5.4 g cal/cm^2 attributed to radiant heat. Based on the average heat exposure a 3.8% body burn area was sustained on the covered body area. Among the five test runs conducted the highest recorded total heat was 12.1 g cal/cm^2, 9.3 g cal/cm^2 attributed to radiant heat. For this fire, the body burn area was 15%, 7% on the upper body and 8% on the lower body.

Table XVI Heat Loads and Burn Data for Lightweight Kynol/Nomex Uniform at 20 Feet From Fire After 100 Seconds Exposure

Total Heat ($g\ cal/cm^2$)	Radiant Heat ($g\ cal/cm^2$)	Body Burn (%)
12.1	9.3	15
7.6	5.8	4
6.4	5.0	0
5.0	3.8	0
4.1	3.2	0
7.0 ± 2.8*	5.4 ± 2.2	3.8 ± 5.8

* Denotes standard deviation.

Heavyweight Kynol/Nomex Uniform

Five test runs were analyzed with the manikin at a distance of ten feet from the fire. Table XVII lists the total and radiant heat levels generated by each fire along with the percent body burn area suffered. The average total heat generated by the fires at this distance was 12.9 g cal/cm^2, 10.1 g cal/cm^2 attributed to radiant heat. Based on the average heat exposure the body burn area was 4.6% of the covered body area. Among the five test runs conducted the highest total heat registered was 22.0 g cal/cm^2, 17.6 g cal/cm^2 attributed to radiant heat. For this fire the body burn area was 15%, 7.0% on the upper body and 8.0% on the lower body.

Table XVII Heat Load and Burn Data for Heavyweight Kynol/Nomex Uniform at 10 Feet From Fire After 100 Seconds Exposure

Total Heat ($g\ cal/cm^2$)	Radiant Heat ($g\ cal/cm^2$)	Body Burn (%)
22.0	17.6	15
13.7	11.0	4
12.7	9.8	4
9.0	6.9	0
6.9	5.1	0
12.9 ± 5.2	10.1 ± 4.3	4.6 ± 5.5

* Denotes standard deviation

Five test runs were also analyzed with the manikin at a distance of 20 feet from the fire. Table XVIII lists the total and radiant heat levels generated by each fire along with the body burn area data. The average heat generated by the fires at this distance was 9.7 g cal/cm^2, 7.6 g cal/cm^2 attributed to radiant heat. Based on the average heat the body burn area was 5.6% of the covered body area. Among the five test runs conducted, the highest total heat registered was 12.8 g cal/cm^2, 10.1 g cal/cm^2 attributed to radiant heat. At this level the body burn area was 8%. None on the upper body and 8% on the lower body.

Table XVIII Heat Load and Burn Data for Heavyweight Kynol/Nomex Uniform at 20 Feet From Fire After 100 Seconds Exposure

Total Heat (g cal/cm^2)	Radiant Heat (g cal/cm^2)	Body Burn (%)
12.8	10.1	8
10.6	8.2	8
10.0	7.9	4
7.8	5.9	4
7.3	5.7	4
9.7 ± 6.7*	7.6 ± 1.6	5.6 ± 1.9

* Denotes standard deviation.

Fire Retardant Treated Cotton Uniform

As with both Kynol/Nomex uniforms five test runs with the cotton uniform were analyzed with the manikin at a distance of ten feet from the fire. Table XIX lists the total and radiant heat levels generated by each fire along with the percent body burn area suffered. The average total heat generated by the fires at this distance was 5.2 g cal/cm^2, 3.8 g cal/cm^2 was attributed to radiant heat. The heat energy generated by these fires was the lowest of all the test runs and no body burns were recorded on the covered body area for 100 seconds. Even for the 9.5 g cal/cm^2 total heat fire no body burns were sustained.

Table XIX Heat Load and Burn Data for FRT Cotton Uniform at 10 Feet From Fire After 100 Seconds Exposure

Total Heat ($g\ cal/cm^2$)	Radiant Heat ($g\ cal/cm^2$)	Body Burn (%)
9.5	8.0	0
7.6	5.3	0
4.5	7.0	0
3.4	2.0	0
1.2	.1	0
5.2 ± 3.0*	3.8 ± 2.6	0 ± 0

* Denotes standard deviation.

Five test runs were analyzed with the manikin at a distance of 20 feet from the fire. Table XX lists the total and radiant heat levels generated by each fire along with the percent body burn area suffered. Whereas the runs at ten feet registered low heat levels, the runs at 20 feet from the fire were among the highest heat levels recorded. The average heat generated by the fires at this distance was 12.1 $g\ cal/cm^2$, 9.4 $g\ cal/cm^2$ was attributed to radiant heat. Based on the average heat value the body burn area was 4.6% of the covered body area at 100 seconds. Among the five test runs conducted, the highest heat level registered was 16.6 $g\ cal/cm^2$, 13.3 $g\ cal/cm^2$ was attributed to radiant heat. For this fire the body burn area was 12% of the covered body area, 4% on the upper body and 8% on the lower body.

Table XX Heat Load and Burn Data for FRT Cotton Uniform at 20 Feet From Fire After 100 Seconds Exposure

Total Heat ($g\ cal/cm^2$)	Radiant Heat ($g\ cal/cm^2$)	Body Burn (%)
16.6	13.3	12
14.2	11.1	12
11.8	9.6	0
9.5	6.9	0
8.1	6.3	0
12.1 ± 3.1*	9.4 ± 2.6	4.6 ± 5.6

* Denotes standard deviation.

Effect of Laundering

To examine the effect of laundering on the uniforms, two test runs were performed on each uniform after the uniforms had been subjected to 15 simulated shipboard launderings. No significant differences were noted in the resulting body burn area data with respect to the new condition.

Discussion

Linear regression curves (Fig. 6) for each of the uniforms show the extent of the estimated burn injury as a function of total heat exposure. Because of the variability of the fires, the total heat loads recorded were more indicative of the burn injury area determined than the distance from the fires. Therefore, the data from the 10 and 20 foot fires were pooled to develop the results shown in Fig. 6. It can be seen that the FRT cotton uniform provided better heat protection for the heat range encountered than either Kynol/Nomex uniform. Both the cotton and HW Kynol/Nomex uniforms provided significantly better protection than the LW Kynol/Nomex uniform. The correlation coefficients for the curves in Fig. 6 related to a confidence level of greater than 95%.

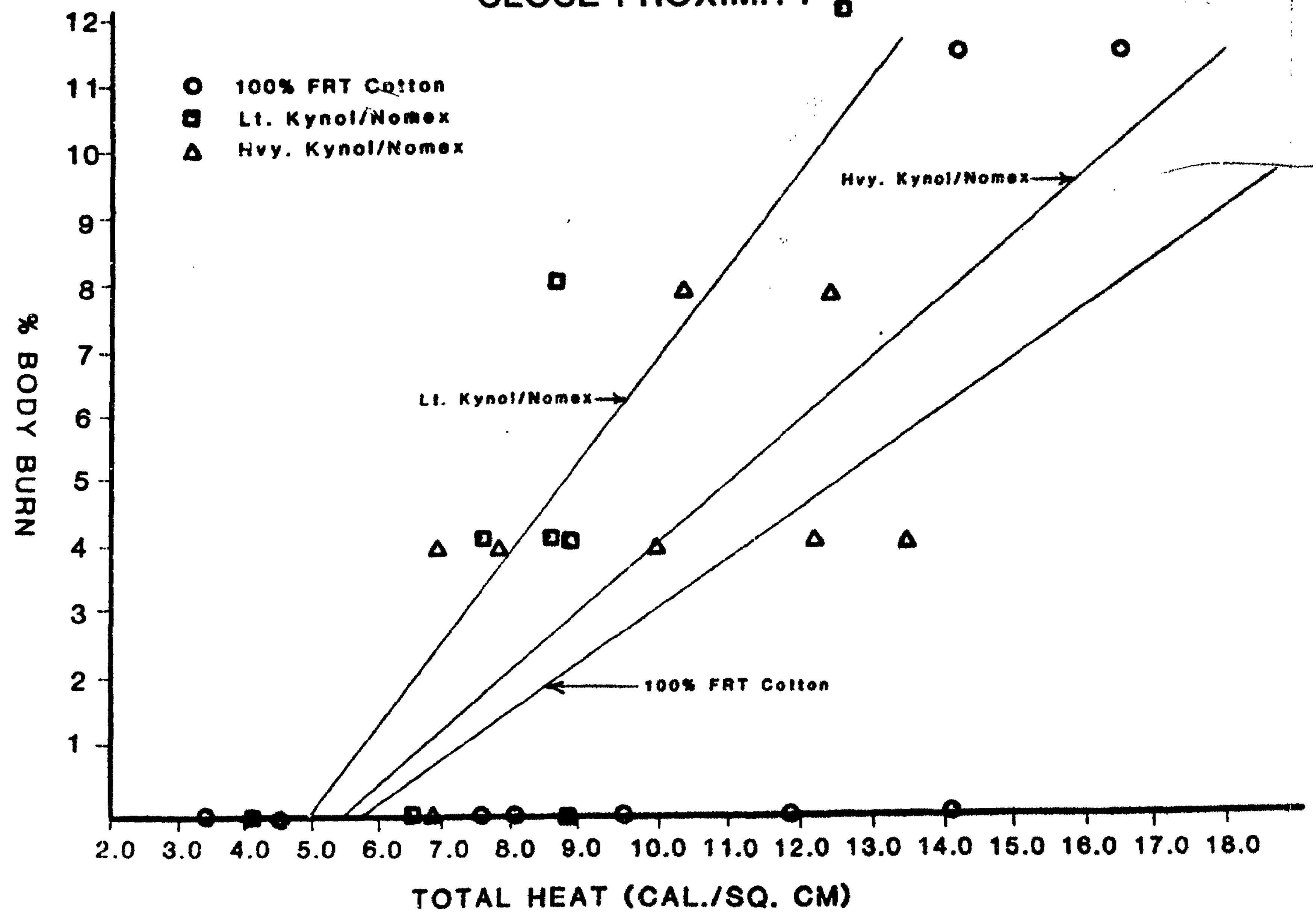
Significance of Burn Injury

As indicated previously under the fire envelopment tests, burns involving more than 20 percent of the body surface area endanger life and 30 percent burns are usually fatal if adequate medical treatment is not received. It was also indicated that the U.S. Army and Air Force when estimating total heat protection provided by a uniform use 20 percent body burn area as the cutoff criteria. Considering this criteria it is quite clear from Fig. 6 that all three uniforms provided protection well below the 20% body burn area criteria at the total heat levels encountered. At a total heat level of 10.0 g cal/cm^2 the body burn area measured for the LW Kynol/Nomex uniform was at least 67% higher than that measured for the HW Kynol/Nomex and FRT cotton uniforms. Analysis of the burn area curves for 0% body burn area show that no burns would have been sustained with the LW Kynol/Nomex uniform at a total heat of 5.0 g cal/cm^2 and approximately 5.5 to 5.7 g cal/cm^2 for the HW Kynol/Nomex and the FRT cotton uniforms.

FIGURE 6

PERCENT BODY BURN VS TOTAL HEAT (CAL./SQ. CM)

CLOSE PROXIMITY



CONCLUSIONS

1. Vertical flammability resistance of the three Kynol/Nomex fabrics and the two FRT cotton fabrics evaluated was excellent initially and after 15 simulated shipboard launderings using Navy shipboard wash formula II. No after flame occurred with any of the samples and the maximum average char length for any 12 inch sample was 3.5 inches.

2. In char through tests none of the Kynol/Nomex and FRT cotton fabrics ignited in radiant heat exposures (0.3 to 1.0 g cal/cm^2/sec). At the highest heat flux level used in these tests (1.0 g cal/cm^2/sec) both cotton fabrics (6.5 oz/yd^2 chambray and 12.0 oz/yd^2 denim) showed significantly lower heat resistance than the three Kynol/Nomex fabrics evaluated (4.5 oz/yd^2, 70/30% blend; 6.0 oz/yd^2, 70/30% blend; and 8.0 oz/yd^2, 80/20% blend). Char through times were 10 and 11 seconds for the cotton fabrics and 34, 38, and 29 seconds for the Kynol/Nomex fabrics. The two 70/30% blend Kynol/Nomex fabrics (4.5 oz/yd^2 and 6.0 oz/yd^2) which had the greater percentage of Nomex showed more resistance to char through (at least 5 seconds greater char through time) than the 8.0 oz/yd^2, 80/20% blend Kynol/Nomex fabric. At char through all of the fabrics disintegrated when touched.

3. In radiant heat protection tests with the fabrics in contact with the heat sensor or one-half inch away from the heat sensor, the time to burn injury (TBI) was related primarily to fabric weight. In most cases for all heat flux levels evaluated the heavier fabric provided the longest protection time regardless of what fiber the fabric was made from. The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton materials. Weight of the fabrics was more a measure of potential burn protection than any other material property.

4. In comparing char through and time to burn injury data for the radiant exposure tests it was noted that the time to burn injury for any of the heat flux levels evaluated would have occurred with the Kynol/Nomex fabrics long before char through would have happened with the FRT cotton fabrics. Thus the benefit of using the higher heat resistant Kynol/Nomex fabrics is somewhat negated since burn injury is sustained with the Kynol/Nomex fabrics long before char through occurs with the cotton fabrics.

5. As with the radiant heat exposure tests, burn protection time in the flame impingement tests was directly related to the weight of the test fabrics and not the particular fibers the fabrics were made from. The heavier the fabric the greater the heat protection time. The Kynol/Nomex materials demonstrated no unique properties for increasing burn time protection with respect to the cotton fabrics.

6. In the two second flame envelopment tests the HW Kynol/Nomex uniform ($6.0\ oz/yd^2$ shirt and $8.0\ oz/yd^2$ trouser), and the FRT cotton uniform ($6.5\ oz/yd^2$ shirt and $12.0\ oz/yd^2$ trouser) showed similar protection characteristics. The average body area burn was 5% at an average total heat of $5.4\ g\ cal/cm^2$ for the FRT cotton uniform versus 4% average total body area burn at an average total heat of $5.0\ g\ cal/cm^2$ for the HW Kynol/Nomex uniform. The protection provided by the LW Kynol/Nomex uniform ($4.5\ oz/yd^2$ shirt and $6.0\ oz/yd^2$ trouser) was at least 44% less than the protection provided by the other two uniform types. The average body area burn for this uniform was 9% at an average total heat level of $4.8\ g\ cal/cm^2$. Based on the average results the relative differences between the uniforms regarding protection after fifteen simulated shipboard launderings were similar to those measured for the new uniforms (Table XI).

7. In tests of uniforms in close proximity to fuel fires (10 and 20 feet) for 100 seconds the FRT cotton uniforms showed greater protection than either the HW or LW Kynol/Nomex uniforms with the HW Kynol/Nomex uniform being more protective than the LW Kynol/Nomex uniform. (Fig. 6).

8. The Kynol/Nomex fabrics/uniforms did not show superior protection/heat resistant characteristics to the FRT cotton fabrics/uniforms in any of the heat protection tests or the vertical flammability tests. Only in the char through tests did the higher thermal resistance of the Kynol/Nomex materials show significant benefit versus the FRT cotton materials. However, body burns would have been sustained with the Kynol/Nomex materials long before char through would have occurred with the cotton materials.

References

1. K. W. Graves, Firefighter's Exposure Study, Cornell Aeronautical Laboratory, Inc., Dec. 1970.

2. Alice M. Stoll, et. al. Method and Rating System for Evaluation of Thermal Protection, Naval Air Systems Command, Dec. 1968.

3. Meredith M. Schoppee, et. al. Resistance of Navy Shipboard Work Clothing Materials to Extreme Heat. Albany International Research, Navy Contract No. N00140-81-C-BA83.

4. NAVEDTRA 10081-N Standard First Air Training Course, 1982.

TAB E

DYEING AND FINISHING STUDY

Introduction

Three fabrics were delivered to Albany International Research Co. for Phases I, II and III of this study. These fabrics were identified as 70/30% Kynol/Nomex, plain weave 4.5 oz/yd^2; 70/30% Kynol/Nomex, plain weave 6.0 oz/yd^2; and 80/20% Kynol/Nomex, twill weave 8.0 oz/yd^2. They are referred to in the work statement as Fabrics A, B, and C respectively. These fabrics are stated to be representative of the material being considered for the manufacture of garments for use by Navy shipboard personnel. Also submitted was fabric dyed to a Navy shade, the approximate shade standard for use in this work.

The objective was to develop commercial dyeing and finishing procedures for imparting a dark blue color with good fastness properties to each of the submitted Kynol/Nomex blended fabrics.

The development work was accomplished through a three phase effort involving laboratory work, Phase I; pilot plant work, Phase II; and production work, Phase III.

The laboratory phase involved the evaluation of dyes and finishes. The information thus obtained was then used to conduct pilot plant work. Finally, the information and procedures developed during the pilot trials were used to conduct full scale commercial dyeing and finishing of the required amount of each of the three fabric blends of Kynol/Nomex fabrics.

The work involved under each of the three phases and the results obtained are described below.

Phase I - Laboratory Work and Results

Prior to starting work under Phase I, it was agreed that of the various tests required for determining fabric characteristics, two of the tests, i.e., dimensional stability and seam efficiency, would be conducted by the U. S. Navy Clothing and Textile Research Facility at Natick; since AI Research Co. does not have the necessary equipment to conduct such tests.

Specimens were removed from each of the submitted fabrics and tested for the type of sizing present, construction and fiber content.

Sizing. A test for the type of size present showed a strong positive test for polyvinyl alcohol. Polyvinyl alcohol is known to be used as a sizing agent in fabric construction. Its removal was accomplished by treating the fabrics with 0.25% solution of caustic soda for 20 minutes at 140°F to 160°F, followed by rinsing and scouring with a 0.25% solution of an anionic surfactant (Witconate 60L, Witco Chemical Corp.) for 20 minutes at 208°F. The amount of Witconate 60L used was based on 100% activity.

It was found that the desizing process caused a shrinkage of 5.5% in the warp direction and 2.0% in the filling direction in both the 4.5 oz/yd^2 and 6.0 oz/yd^2 fabrics. The 8.0 oz/yd^2 fabric showed 5.5% shrinkage in the warp and 0.69% in the filling direction. Presumably, the cause of the 5.5% shrinkage in the warp direction in each of these fabrics is due to the relaxation of strains introduced during fabric manufacture.

Construction. Examination of each of the submitted fabrics confirmed the announced construction in the work statement, i.e.,

Fabric A, plain weave
Fabric B, plain weave
Fabric C, twill weave.

Fiber Content. Examination with the aid of a microscope showed that each of the fabrics contained the nominal blend specified in the work statement, i.e.,

Fabric A, 70/30 Kynol/Nomex
Fabric B, 70/30 Kynol/Nomex
Fabric C, 80/20 Kynol/Nomex.

Fabric Characteristics

Tests were conducted in accordance with test methods specified in the work statement to determine the fabric characteristics of the desized undyed fabrics. The results are shown in Table 1.

Dyeing and Finishing

Dyeing. A number of cationic and dispersed dyes were obtained for dyeing the submitted desized fabrics. In addition, it was decided that benzyl alcohol would be used as the dyeing assistant. The dyes evaluated are shown in Table 2.

Cross sections of yarns in dyed fabrics showed that the use of 60 grams/liter of benzyl alcohol is sufficient to cause dye penetration into the Kynol and most of the Nomex fibers when dyed for 60 minutes at 265°F.

It is known that Kynol fiber can be dyed with either cationic or dispersed dyes. The Nomex fiber is not dyed with dispersed dyes, but can be dyed with cationic dyes. Additionally, the Kynol fibers in their natural state are colored yellow whereas the Nomex fibers are white. Since the major fiber component in all the submitted blends consists of Kynol, its yellow coloration has to be considered in the formulation of dyes to achieve a desired shade.

Based on these considerations, it was decided that the desired Navy shade on the submitted fabrics would be formulated by: (1) dyeing both the Kynol and Nomex fibers with cationic dyes; or (2) dyeing the Kynol and Nomex fibers with a combination of dispersed and cationic dyes.

Dyeing trials were performed to first establish the shades that could be expected with individual dyes. During this work, the results indicated that the dyeing process caused shrinkages of approximately 4% in the warp direction and 5% in the filling direction of Fabric A. Presumably, somewhat similar shrinkages could be expected with Fabrics B and C. These shrinkage figures were considered at best approximations since plant processing might result in decreased shrinkage due to the equipment used during wet processing, and that used during drying/curing of the finished fabrics.

Table 1. Undyed Fabric Characteristics

Property	Test Method	Sample A		Sample B		Sample C	
Weight (oz/yd^2)	5041	4.9		6.5		8.4	
Weave	visual	plain		plain		$\frac{1}{2}$ twill	
		Warp	Filling	Warp	Filling	Warp	Filling
Tensile Strength (lbs)	5100	95	82	131	94	145	120
Tear Strength (1x10^2 gm)	5132	29	27	29	17	37	28
Threads per Inch	5050	52	46	80	46	78	50
Air Permeability (cu ft air/min/ft^2 fabric)	5450	94		17		28	
pH	2811	6.6	6.7	7.0	7.2	7.1	7.0
Nonfibrous Content	2611	3.9		3.4		3.1	
Flammability* (char length in.)	5903	2.450	2.900	2.300	2.175	2.000	1.825
Yarn Ply	visual	2 ply (w + f)		2 ply (w + f)		2 ply (w + f)	
Abrasion (cycles)	5302	30		90		270	

*The specimens did not exhibit an after glow or after flame.

Table 2. Dyes Evaluated for Use in the Coloration of Kynol/Nomex Blended Fabrics

Cationic Dyes

Synacril Blue 2B
Sevron Fast Blue GLK
Sevron Blue 5G
Sevron Blue 2G
Sevron Blue B
Sevron BR Red BN
Sevron Brilliant Red 4G
Sevron Fast Red CBL
Sandocryl Blue B3G
Sandocryl Blue B-RLE
Sandocryl Red BBL
Sandocryl Yellow BGL
Basacryl Blue X3GL
Genacryl Orange G (21)

Dispersed Dyes

Foron Dark Blue RD-2RE
Foron Blue RDGLF
Foron Blue RDGLA
Foron Blue 3GLA
Foron Navy RD2RLA
Foron Navy RDRLS
Foron Black RDRLA
Foron Red RDGLA
Foron Scarlet RD2GLA
Foron Rubine 2D2BLA
Foron Orange RD2RL
Foron Yellow S6GL
Foron Yellow RD4GLS
Foron Yellow RD4GRLA
Celliton Fast Red Violet RNA
Dispersol Blue C4RA Grains
Dispersol Blue BR Grains
Dispersol Blue 3RLN
Dispersol Navy P3GRA
Dispersol Navy C2GAPDR
Dispersol Navy BT200GR
Dispersol Navy D3 GRA
Dispersol Yellow D7G PdR
Intrasil Blue 3RLN
Intrasil BR Red
Intrasil Red MG

Mock dyeing (exposure of fabric to the dyebath without dye) showed that the Kynol component becomes brighter in shade. However, during drying, the Kynol component darkens with increasing temperature and time. Furthermore, exposure of mock dyed fabric to a carbon arc lamp showed that it darkens after exposure to 5 standard fading hours. Such poor stability to light is considered a shortcoming, since such a change will inevitably decrease the colorfastness of light of the dyed fabrics, since it will lead to a shade change (darkening) in 5 hours.

Additionally, it was found that drying of the fabric at 300°F for 5 minutes following dyeing and scouring produces an appreciable color change in the final shade. However, commercial drying seldom involves dwell times of 5 minutes. Hence, it is unlikely that commercial drying practices would detrimentally affect the final shade of the dyed fabric.

Scouring of the fabric following dyeing serves two purposes; (1) it permits removal of excess dye; and (2) it removes adsorbed benzyl alcohol to a point where it does not detrimentally affect the fabric's inherent resistance to flammability.

Cationic Dye Formulations. Attempts to obtain the desired Navy shade using cationic dyes showed that the dyes selected did not yield shades that could be formulated to obtain an approximate match to the submitted standard. Hence, further work with this approach was abandoned.

Dispersed/Cationic Dye Formulations. The use of a combination of dispersed and cationic dyes produced shades which led to a formulation that produced a shade approximating that of the submitted standard. The formulations are shown in Table 3. The procedure follows.

The dye formulation (see Table 3) was applied to sufficient fabric which was subsequently treated with each of the three finish formulations referred to as Duro and AI Research Co. #1 and #2. The results of tests on the dyed and finished fabrics are shown in Tables 7, 8 and 9. These tests include colorfastness to light, laundering, crocking, perspiration, as well as flammability and pH.

Finishing. It was learned that from the Project Monitor, Mr. Richard Wojtaszek, that the antistatic and permanent press finish required to be applied to the dyed samples is the same treatment which the Navy has had applied to undyed fabric for evaluation in the field. The finish formulation and the details of application to desized undyed Kynol/Nomex blended fabrics were obtained from the Duro Finishing Co. A review of that formulation (see Table 4) showed that it does not contain an antistat. The Project Monitor agreed that the formulation as given (without antistat) should be applied to the dyed fabric samples to be included in Phase I.

It was also agreed that the laboratory dyed samples (A, B and C) should be submitted with the following treatments: (1) dyed without any resin treatment, (2) dyed with the addition of an antistatic and durable press treatment (described by Duro Finishing Co.), and (3) dyed with a treatment to improve abrasion resistance in combination with a durable antistat.

Table 3. Dye Formulation and Procedure Used for the Coloration of Kynol/Nomex Blended Fabrics (Laboratory Work)

All dyeings were based on a 40:1 water/fabric weight ratio (see below). All dyeings were performed using 60 grams/liter benzyl alcohol, 5 grams/liter Witconate 60L (based on 100% activity) and 5% formic acid (85%) based on the weight of fabric.

Fabric Identification	Name of Dye	Manufacturer	Generic Name	Color Index No.	Amount Used (%)*
A	Celliton Fast Red Violet RNA**	GAF	Disperse Violet 1	61100	4.5
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
B	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	4.5
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
C	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	5.3
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	2.5

*Based on the weight of fabric.
**Also available from Atlantic Industries and Crompton Knowles Corp.

Procedure: The required amount of benzyl alcohol was combined with Witconate 60L and then added to water to obtain a dispersion of the benzyl alcohol. This dispersion was then added to the wet-out fabric. After approximately 5 minutes of agitation, formic acid was added followed by the required amount of dissolved and diluted dyes. The fabric was agitated in the dyebath for approximately 5 minutes at room temperature. The stainless steel container was then closed and loaded into a LaunJer-Ometer containing ethylene glycol as the heating medium. The rate of rise was set at 5.5°F/min. After reaching 265°F the bath temperature was maintained for 60 minutes.

Following the cool down cycle the fabric was rinsed with hot water and then scoured.

Scouring of Dyed Fabric: The fabric was scoured for 20 minutes at 180°F with 1 gram/liter trisodium phosphate and 1.5 grams/liter Witconate 60L (based on 100% activity), then rinsed with warm water. This procedure was repeated twice. The scoured fabric was then passed between squeeze rolls to remove excess water, and then dried for 5 minutes at 300°F.

Table 4. Duro Durable Press Finish Formulation* and Procedure
(Based on 95% Wet Pickup)

Product Name	Supplier	Amount of Product (%) Based on Weight of Bath
CNC Wet CP	CNC Chemical Co.	0.15
CNC Rez PV	CNC Chemical Co.	2.44
CNC Mel 80-P	CNC Chemical Co.	0.61
Bersil 4586 (Bersen Reactive Silicone Softener)	Bersen, Inc.	1.83

*Obtained from Duro Finishing Company.

Procedure: Dyed samples of Fabrics A, B and C were immersed one at a time into the finish formulation then passed between squeeze rolls to remove excess liquid. The samples were then placed on pin frames and dried for 3 minutes at 330°F in a forced draft area. The time of temperature recovery to 330°F after inserting the sample into the oven was approximately 20 seconds.

The results of flammability tests on these samples showed essentially no after glow or after flame (see Table 7).

Efforts were made to improve the abrasion resistance of the Kynol/Nomex blended fabrics by addition of a finish. The work was conducted on Fabric A, since it exhibited the poorest resistance to abrasion (see Table 1).

Desized undyed specimens were removed from submitted Fabric A and treated with three different concentrations of each of the three products. The add-on, based on the dry weight of fabric, was varied to deposit 1%, 2% and 4% solids. The results are shown in Table 5.

The values of Table 5 show that Butvar Dispersion BR Resin is an effective additive for increasing the fabric's resistance to abrasion. However, the addition of these products at or above the 2% add-on level does increase the fabric's stiffness. Based on these results, a finish formulation was prepared using the Butvar dispersion, softener and antistatic product and applied to the dyed fabric samples. This finish formulation is shown in Table 6 and is referred to as AI Research Finish #1.

The results of flammability tests on these samples showed significant after glow and no after flame (see Table 8). As a result of this finding, the formulation was carefully scrutinized for the product(s) causing the unacceptable after glow. It was learned that the use of the antistat, either Onyxstat or Aston 123 and the accelerator DT caused the after glow. Since one of the main objectives of this work was to maintain the fabric characteristics of the untreated fabric, it was decided that although the addition of a durable antistat is required and desirable, it should be omitted. Hence, the antistat was not included in the Duro formulation, nor was it or the softener included in the formulation involving the use of the Butvar dispersion. The fabrics treated with a diluted mixture of Butvar dispersion involved a dry add-on of approximately 1.0% to improve their resistance to abrasion. This treatment is referred to as AI Research Formulation #2.

Table 5. The Effect of Additives on the Abrasion Resistance of Undyed Kynol/Nomex Blended Fabric (Fabric A, Test Method 5302)

Product Name	Supplier	Add-on (%)	Abrasion Resistance Cycles*
Original, untreated	--	--	30
Rhoplex B-15	Rohm & Haas	1	33
		2	33
		4	61
Butvar Dispersion BR Resin	Monsanto	1	69
		2	94
		4	109
Polyurethane 1013	White Chemical Corp.	1	39
		2	49
		4	59

*Each value represents an average of three tests.

Table 6. AI Research Co. Finish Formulation #1 and Procedure (Based on 95% Wet Pickup)

Product Name	Supplier	Amount of Product (%) Based on Weight of Bath
Butvar Dispersion BR Resin	Monsanto	2.10
Bersil 4536	Bersen, Inc.	1.82
Onyxstat	Lyndal Chemical Gia*	10.30
Accelerator DT	Lyndal Chemical Gia*	1.03

*Division Millmaster Onyx Group.

Procedure: Dyed sample of Fabrics A, B and C were immersed one at a time into the finish formulation then passed between squeeze rolls to remove excess liquid. The samples were then placed on pin frames and dried for 3 minutes at 300°F in a forced draft oven. The time of temperature recovery for some of the treated samples varied as long as 2 minutes after entry into the oven. This delay caused the fabrics to darken in shade.

The results of flammability tests on samples treated with each of the finish formulations are shown in Tables 7, 8 and 9. The use of the Duro finish or AI Finish #2 (each without antistat) showed essentially no after glow or after flame. However, AI Finish #1 showed significant after glow and no after flame.

Test Results

Duro Finish. The tests on finished fabrics using the Duro supplied finish formulation (see Table 7) show that, although the color of the fabrics was not significantly affected by laundering, the nylon fibers in the multitest fabrics were stained to an unacceptable degree indicating that dye was leached out of the dyed fabric.

The perspiration fastness was rated good for Fabric A and excellent for Fabrics B and C.

Exposure to 20 standard fading hours caused all samples to fail. This was not unexpected since undyed Kynol is known to darken when exposed to light for 5 standard fading hours.

The crocking test results show that in all fabrics the dry crocking is better than wet.

The flammability test results, when compared to the desized undyed fabrics, show that dyeing and finishing of the fabrics did not detrimentally affect their inherent resistance to flammability.

AI Research Finish #1. The tests on AI Research Finish #1 (see Table 8) show that although the color of the fabrics was not significantly affected by laundering, the nylon fibers in the multifiber test fabrics were stained to an unacceptable degree indicating that dye was leached out of the dyed fabric.

The perspiration fastness was found to vary among these samples. For example, Fabric A exhibited no significant change in color in either the alkaline or acid conditions. However, the acetate and nylon fibers in the multifiber test fabric were stained to an unacceptable degree. Fabric B was rated as fair in both color change and staining after both alkaline and acid testing, whereas Fabric C was rated as excellent after similar testing.

Exposure to 20 standard fading hours caused all samples to fail, since the Kynol fiber darkened during exposure to light.

The crocking test shows that the wet crocking results for Fabrics A and B were rated as fair, whereas Fabric C was rated good. All fabrics were rated as good for dry crocking.

The flammability test results, when compared to the desized undyed fabrics, showed that although the char lengths were unaffected, the after glow times were appreciable.

Table 7. Colorfastness and Flammability Properties of Finished Fabrics
(Laboratory Work)

Fabric Identification	Laundering, Test Method 5610		Perspiration, Test Method 5680		SFH	Crocking, Test Method 5651		pH,	Flammability, Test Method 5903					
	Color Change	Staining	Alkaline Color Change	Acid Color Change	Light,				Char Length (inches)		After Glow (seconds)		After Flame (seconds)	
Duro Finish	Pass or Fail	Pass or Fail	Staining	Staining	TM 5660	Wet	Dry	TM 2811	Warp	Fill	Warp	Fill	Warp	Fill
Fabric A	Pass	Fail	Good	Good	Fail 20	Fair	Good	5.4	1.750	1.650	0	0	0	0
		A* Fair												
		C Excellent												
		N Poor												
		P Excellent												
		A Excellent												
		W Good												
Fabric B	Pass	Fail	Excellent	Excellent	Fail 20	Fair	Good	6.0	1.738	1.325	0	0	0	0
		A* Good												
		C Excellent												
		N Poor												
		P Excellent												
		A Excellent												
		W Excellent												
Fabric C	Pass	Fail	Excellent	Excellent	Fail 20	Fair	Excellent	6.1	1.200	0.975	0	0	1.4	0
		A* Good												
		C Excellent												
		N Poor												
		P Excellent												
		A Excellent												
		W Excellent												

Calibration
L-4
Wool Standard

SFH = Standard Fading Hours

Key: *A=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.

Table 8. Colorfastness and Flammability Properties of Finished Fabrics
(Laboratory Work)

Fabric Identification AI Finish #1	Laundering, Test Method 5610: Color Change Pass or Fail	Laundering, Test Method 5610: Staining Pass or Fail	Perspiration, Test Method 5680, Alkaline: Color Change	Perspiration, Alkaline: Staining	Perspiration, Acid: Color Change	Perspiration, Acid: Staining	SFH Light, TM5660	Crocking, Test Method 5651: Wet	Crocking: Dry	pH, TM 2811	Flammability, Test Method 5903: Char Length (inches) Warp	Char Length (inches) Fill	After Glow (seconds) Warp	After Glow (seconds) Fill	After Flame (seconds) Warp	After Flame (seconds) Fill
Fabric A	Pass	Fail	Pass	Fail	Pass	Fail	Fail 20	Fair	Good	7.4	2.125	2.250	102.2	102.8	0	0
		A* Fair		A* Poor		A* Poor										
		C Excellent		C Excellent		C Excellent										
		N Poor		N Poor		N Poor										
		P Excellent		P Excellent		P Excellent										
		A Excellent		A Excellent		A Excellent										
		W Good		W Fair		W Fair										
Fabric B	Pass	Fail	Fair		Fair		Fail 20	Fair	Good	8.0	1.525	1.425	129.2	118.8	0	0
		A* Fair														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Good														
Fabric C	Pass	Fail	Excellent		Excellent		Fail 20	Good	Good	8.2	0.837	0.900	131.2	124.6	0	0
		A* Fair														
		C Excellent														
		N Poor														
		P Excellent														
		A Excel'ent														
		W Good														
Calibration L-4 Wool Standard																

SFH = Standard Fading Hours

Key: *A=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.

Table 9. Colorfastness and Flammability Properties of Finished Fabrics
(Laboratory Work)

Fabric Identification	Laundering, TM 5610		Perspiration, Test Method 5680				SFH Light,	Crocking, TM 5651		pH,	Flammability, Test Method 5903					
	Color Change	Staining	Alkaline		Acid						Char Length (inches)		After Glow (seconds)		After Flame (seconds)	
AI Finish #2	Pass or Fail	Pass or Fail	Color Change	Staining	Color Change	Staining	TM 5660	Wet	Dry	TM 2811	Warp	Fill	Warp	Fill	Warp	Fill
Fabric A	Pass	Fail	Good		Good		Fail 20	Good	Good	6.5	2.350	2.350	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric B	Pass	Fail	Good		Good		Fail 20	Good	Good	6.9	2.425	2.100	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric C	Pass	Fail	Good		Good		Fail 20	Fair	Good	7.0	1.575	1.425	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Calibration L-4 Wool Standard																

SFH = Standard Fading Hours

Key: *A=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.

AI Research Finish #2. The tests on AI Research Finish #2 (see Table 9) show that, although the color of the fabric was not significantly affected by laundering, the nylon fibers in the multifiber test fabrics were stained to an unacceptable degree indicating that the dye leached out of the dyed fabric.

The perspiration fastness was rated as good on all samples.

Exposure to 20 standard fading hours caused all samples to fail, since the Kynol fiber darkened during exposure to light.

The crocking tests were rated as good for all fabrics, except for wet test on Fabric C which was rated as fair.

The flammability test results, when compared to the desized undyed fabrics show that dyeing and finishing of the fabrics did not detrimentally affect their inherent resistance to flammability.

Discussion and Conclusions. The laboratory work showed that Kynol/Nomex fabrics can be dyed to approximate the desired Navy shade. The obvious shortcoming is the natural yellow coloration of the Kynol fiber, which did affect color formulation.

The results of testing of the dyed finished fabrics showed that satisfactory properties - such as resistance to perspiration, crocking, and flammability - were obtained. The colorfastness to laundering met the requirement for color change, however, the nylon component in the multifiber test fabric absorbed significant amounts of dye indicating that the dye leached out of the dyed fabric. Consequently, it was rated as poor.

It is obvious that the range of dyes that might be used to dye Kynol/Nomex blended fabrics is considerably more extensive than those shown herein. Furthermore, it is reasonable to expect that other dyes can yield shades which exhibit better wet fastness properties. However, it should be recognized that despite the strong likelihood that better wet fastness can be achieved, the sensitivity of the Kynol to light will result in appreciable shade changes (darkening) which will preclude acceptability of shades which are tested by exposure to a carbon arc light source.

The problem of the darkening of Kynol fiber during exposure to heat was taken into consideration during color matching.

The application of the durable antistats require a fixing agent and/or catalyst to obtain durability to laundering. The use of the Onyxstat product was stated to yield less yellowing than the Aston 123. For this reason, the first formulation included the Onyxstat product. When it was learned that its application caused unacceptable after glow after testing for flammability, the product Aston 123 was substituted. Again, the same problem was encountered. Based on these results, it appears that durable antistats do cause a problem with after glow, and might explain why the Duro formulation omitted use of the antistat. These results should not be misinterpreted to mean that a durable antistat cannot be applied to Kynol/Nomex blends. Their use most likely will have to be accompanied by a flame retardant product in order to meet flammability requirements.

The successful laboratory application of dyes to achieve an approximation to the desired Navy shade was based on the selection of cationic and dispersed dyes. The Kynol fiber absorbs dyes at a faster rate than Nomex. Hence, although tone on tone was expected, and in fact obtained, the dyeings appear as solid shades because the Kynol fiber is the major component in all of the blends studied, and served to "carry" the shade.

Phase II - Pilot Plant Trial

Fabric Preparation (Desizing). Laboratory work had clearly indicated that the dyed Kynol/Nomex fabrics developed wrinkles/cracks that could not be removed once they had set. In order to minimize their occurrence during pilot plant dyeing, it was decided that the required amount of fabric would be scoured and dried in open width form. The work was performed at Tweave, Inc. located in Norton, MA.

The fabrics (A, B and C, total 128 yards) were loaded onto a jig (100 gallon capacity) while passing through warm water. The tension adjustment on the Vald Henriksen Jig was set at the lowest point possible consistent with control of the fabric as it passed through the standing bath at 50 yds/min. This fabric speed was maintained throughout scouring and rinsing.

The fabric was treated with 0.25% solution of sodium hydroxide for 20 minutes at 140°F. The bath was then dropped and the fabric rinsed. The fabric was next treated in a new bath containing 0.25% solution of Witconate 60L (based on 100% activity) for 20 minutes at 200°F. The fabric was then given an overflow rinse at 160°F followed by two subsequent rinses with warm water. Each of the two rinses consisted of a fresh bath at 120°F.

The fabric was dried by allowing it to pass over a vacuum slot to remove as much water as possible and then passed onto drying cans having a surface temperature in the range of 250°F. The dried fabric was then batched.

Dyeing and Finishing. The dyeing and finishing work was performed at Native Textiles, located at Glens Falls, NY, on January 31 and February 1, 1985.

The plant trial work was based on the formulations developed under Phase I. The dye formulations were adjusted to conform to pilot plant dyeing equipment as well as to meet a shade deemed to be acceptable by NCTRF.

The finish formulation applied to the dyed fabrics, with the approval of NCTRF, was based on the use of Butvar dispersion (Monsanto). This product was used to impart improved abrasion resistance to the fabrics.

Fabrics A and B were joined to form an endless rope and dyed in a Gaston County 80 lb capacity jet dyeing machine. Fabric C was dyed in a Gaston County 5.75 lb capacity jet dyeing machine. In each case, a program profile was established which automatically controlled the operation of each machine. The program involves a controlled temperature rise of 3°F/min to 265°F, and a hold at that temperature for 60 minutes. The cool down cycle was set at 3°F/min to a temperature of 160°F, at which time "patch" samples were removed for examination of shade.

The first trial involved the use of Native Textile's smaller jet dyeing machine and 5.4 lb of Fabric C (8.5 yards). The formulation for Fabric C was established by starting with the formulation developed in our laboratory and additions were made during the run to arrive at a shade deemed to be acceptable by NCTRF, whose representatives were present at the trial. The formulation was then duplicated in a second trial using 7.1 lbs (11 yards) of Fabric C. Unfortunately, the overloading of the small laboratory machine during this trial caused unacceptable streaks in the fabric.

The starting formulation for Fabrics A and B, total weight 42 lbs (103 yards), was that developed at AI Research Co., additives were made as required.

Following dyeing, all the fabrics were scoured and finished. The dye, scour and finish formulations and procedures are included in Table 10. It should be noted that the sodium hydrosulfite was introduced into the scouring formulation to assist in the removing of surface dye that could detrimentally affect wet fastness properties. It was found that the use of sodium hydrosulfite helped to brighten the final shade on the fabrics.

Visual inspection of the dyed and finished fabrics clearly showed that the dyeing cycle used prevented the formation of wrinkles/cracks in the fabrics.

The physical properties of the undyed and the finished fabrics are shown in Table 11, and the colorfastness and flammability properties are shown in Table 12.

It was agreed with NCTRF that the required dimensional stability test would be conducted at their laboratories, since AI Research Co. does not have the necessary equipment to conduct such tests. Furthermore, it was agreed that there was no need to conduct antistatic tests before or after laundering or the testing for permanent press properties since the finish formulation did not contain additives which would impart such properties.

Discussion and Conclusions. The results in Table 11 show that the dyed fabric properties are, in general, better than those of the undyed fabrics. The action of washing, dyeing, finishing and drying allowed the fabrics to shrink slightly, as shown by the yarn count; has probably bulked and flattened the yarns somewhat, so the permeability of Fabric C is reduced; and has doubtless relaxed residual strains permitting a more uniform stress distribution and, consequently, a higher measured breaking strength. The tear strength was increased, probably as a result of the lubricating action of the finish which permits easier bunching of the yarns during tearing and, consequently, improved load support. This finish has also improved the abrasion resistance by a factor of as much as 4.

Table 12 shows that the colorfastness properties are generally fair to good, as they were in the laboratory dyeings. Colorfastness to laundering and perspiration is acceptable, but staining on the acetate and nylon test fabrics in a wash test was excessive indicating that dye was leached out of the dyed fabric. It is possible that this could be improved somewhat by scouring the fabric more thoroughly after dyeing. However, because of the

Table 10. Dye Formulation and Procedure Used for the Coloration of Kynol/Nomex Blended Fabrics (Phase II)

All dyeings were performed using 60 grams/liter benzyl alcohol, 5 grams/liter Witconate 60L (based on 100% activity) and 5% formic acid (85%) based on the weight of fabric.

Fabric Identification	Name of Dye	Manufacturer	Generic Name	Color Index No.	Amount Used (%)*
A	Celliton Fast Red Violet RNA**	GAF	Disperse Violet 1	61100	7.25
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
B	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	7.25
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	5.0
C	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	7.6
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	2.5

*Based on the weight of fabric.
**Also available from Atlantic Industries and Crompton Knowles Corp.

Dyeing Procedure: The required amount of benzyl alcohol was combined with Witconate 60L and then added to the wet-out fabric in the machine. After 5 minutes, formic acid was added followed by the required amount of dissolved and diluted dyes. Following another holding period of 5 minutes the temperature was raised in accordance with the established program profile (see text).

Scouring Procedure: The fabric was scoured for 30 minutes at 185°F with 1 gram/liter trisodium phosphate, 1.0 gram/liter Witconate 60L (based on 100% activity) and 1.0 gram/liter sodium hydrosulfite. The fabric was finally given two rinses with warm water before removal from the jet machines.

Finishing Procedure: The dyed scoured fabrics were passed into a trough overflowing with warm water to permit complete wetting and also to provide an additional rinse. The fabrics next allowed to pass between squeeze rolls to remove excess water and to provide a uniform water content (approximately 70% wet pick up) prior to drying. The drying was performed on an Artos pin frame set at 250°F, and a running speed of 8 yds/min. After drying the fabric was passed through a diluted Butvar dispersion sufficient to yield a 1% dry add-on of the product. The temperature of drying/curing was increased to 300°F and the speed of the Artos pin frame to 10 yds/min during the application of the finish.

Table 11. Fabric Characteristics (Phase II)

Property	Test Method	Condition	Sample A		Sample B		Sample C*	
			Warp	Fill	Warp	Fill	Warp	Fill
Weight (oz/yd^2)	5041		5.4		7.4		9.7	
Breaking strength (lbs)	5100	undyed	95	82	131	94	145	120
		dyed	120	94	185	97	190	132
Tear strength ($1x10^2$ gms)	5132	undyed	29	27	29	17	37	28
		dyed	35	32	36	21	36	24
Thread/inch	5050	undyed	52	46	80	46	78	50
		dyed	56	48	82	49	84	53
Air permeability (cu ft air/min/ft^2 fabric)	5450	undyed	94		17		28	
		dyed	96		23		14	
Abrasion (cycles)	5302	undyed	30		90		270	
		dyed	125		318		628	

*This fabric was processed in the small laboratory jet dyeing machine, whereas Fabrics A and B were processed together in a larger laboratory machine.

Table 12. Colorfastness and Flammability Properties of Finished Fabrics (Phase II)

Fabric Identification BR Dispersion Finish	Laundering, TM 5610 Color Change Pass or Fail	Laundering, TM 5610 Staining Pass or Fail	Perspiration, Test Method 5680 Alkaline Color Change	Alkaline Staining	Acid Color Change	Acid Staining	SFR Light TM 5660	Crocking TM 5651 Wet	Crocking TM 5651 Dry	pH, TM 2811	Flammability, Test Method 5903 Char Length (inches)** Warp	Char Length Fill	After Glow (seconds) Warp	After Glow Fill	After Flame (seconds) Warp	After Flame Fill
Fabric A	Pass	Fail	Good		Good		Fail 20	Fair	Fair	6.7	1.900	2.150	0	0	0	0
		A* Poor														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric B	Pass	Fail	Good		Good		Fail 20	Good	Fair	6.2	2.000	1.450	0	0	0	0
		A* Poor														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric C	Pass	Fail	Good		Good		Fail 20	Good	Fair	5.6	2.250	2.050	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														

Lamp calibration (SFR)
L-4
Wool standard

Key: *=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.

**Values for the undyed fabrics

	Char Length (in.) Warp	Fill
A	2.450	2.900
B	2.300	2.175
C	2.600	1.825

no after glow or after flame

apparent ease with which the dispersed dye can be washed out of the fiber, long-term colorfastness to laundering may prove to be a problem. If this does occur, the cause is undoubtedly related to inadequate attachment of the dye molecules to the Kynol fiber, which might be improved if sufficient effort was made to locate a more suitable dyestuff.

Lightfastness is again poor because of the inherent nature of the phenolic fiber, which darkens rapidly on exposure to light. The effects of this darkening cannot be masked by dyeing.

The flammability resistance of the dyed fabric is somewhat better than that of the undyed fabric. In any case, the values indicate excellent flame resistance.

The results obtained in Phase II established that that system developed for the application of dyes and finish could be used in production work.

Phase III - Production, Preparation, Dyeing and Finishing

The entire amount of fabric required for Phase III was supplied by NCTRF. Fabric preparation, dyeing and finishing was performed at Native Textiles.

Based on additional laboratory work, evidence was obtained which indicated that the use of longer dyeing time, at a higher dyeing temperature, could produce higher dye exhaustion thereby effecting a reduction in the amount of dye required to obtain the desired Navy shade.

The entire process involving preparation (desizing), dyeing and scouring was performed on full size production Gaston County jet dyeing machines. Fabrics A and B were dyed together in one machine and Fabric C dyed separately in another machine. In each case, a program was developed and introduced into the computer that controlled each jet dyeing machine.

All the chemicals used during this production work were based on 400 gallons of total volume. This liquid capacity had to be maintained in order for the machine to operate properly. Each machine was rated as being capable of processing 225 lbs of fabric, this was considerably more than the actual weight of fabric processed in each machine. In other words, the machines were underloaded. Hence, the use of the full capacity of each machine (pounds of fabric) would have served to lower the cost per yard of dyed fabric (see below).

Greige Fabric Inspection. Inspection of the fabric prior to dyeing revealed that Fabric A contained filling bands, oil and dirt spots and missing filling. Fabric B was found to have loose selvages, some oil and dirt spots. Fabric C exhibited heavy deposits of sizing (polyvinyl alcohol) and oil spots.

Preparation (Desizing) and Dyeing. Following the loading of Fabrics A and B, total weight 181 lbs, (432 yards) into the jet machine they were treated with 8 lbs of sodium hydroxide for 20 minutes at 160°F. The bath was then dropped and the fabrics rinsed for 10 minutes at 120°F. The fabrics were scoured with 3 lbs of Witconate 60L (100% Active) for 20 minutes at 210°F and rinsed for 10 minutes at 120°F.

The chemical additives to the dyebath included 200 lbs of benzyl alcohol, 29.5 lbs of Witconate 60L (56% Active), and 16.5 lbs of formic acid (85%). The benzyl alcohol was mixed with the Witconate 60L prior to being added to the standing bath in the jet dyeing machine. The formic acid was used to wet out and assist in the solvation of the required amount of basic dye. The dissolved basic dye was added to the dyebath first. Then the dispersed dye in water was added to the dyebath. The dye formulations for each of the fabrics are shown in Table 13.

The dyeing cycle involved raising the temperature of the dyebath at 4°F/min to 245°F, then at 3°F/min to 275°F. After 90 minutes at temperature (275°F), the bath temperature was dropped at 3°F/min to 140°F. A sample was then cut to examine it for shade.

Following the examination of the first sample, the dyebath was dropped and the fabrics rinsed for 5 minutes at 120°F and then scoured.

The scouring involved the addition of 4 lbs of sodium hydrosulfite and 7 lbs of Witconate 60L (56% Active) to the bath, which was heated to 180°F at the rate of 4°F/min. After 20 minutes the bath was cooled to 130°F at the rate of 3°F/min and then dropped. The fabric was given two separate rinses, each at 120°F for 5 minutes, unloaded, and held for drying and finishing.

Fabric C, total weight 141 lbs, (220 yards), except for the amount of dyes added, was treated in exactly the same manner as Fabrics A and B. Following the examination of the first sample following the dyeing cycle, the bath was dropped and the fabric scoured as above, except that 4 lbs of trisodium phosphate was added in addition to the stated amounts of sodium hydrosulfite and Witconate 60L. The fabric was unloaded and held for drying and finishing.

Finishing Procedure. Fabrics A and B were processed together. Fabric C was processed separately.

Fabrics A and B were passed into a trough overflowing with warm water to permit wetting and also provide an additional rinse. They were next allowed to pass between squeeze rolls to remove excess water and to provide a uniform water content (approximately 70% wet pick up) prior to drying. The drying was performed on an Artos pin frame set at 325°F and a running speed of 18 yds/min.

Fabric C was processed in the same manner as Fabrics A and B except that it was passed through the Artos pin frame at 325°F and a running speed of 10 yds/min.

After drying, Fabrics A and B were passed through a diluted Butvar dispersion sufficient to yield a 1% dry add-on of the product. The drying/curing temperature and the running speed of the Artos pin frame was the same as used to previously dry the fabric.

Fabric C was treated the same as Fabrics A and B, the drying/curing temperature and the running speed of the Artos pin frame was the same as used to previously dry the fabric.

Table 13. Dye Formulation and Procedure Used for the Coloration of Kynol/Nomex Blended Fabrics (Phase III)

Fabric Identification	Name of Dye	Manufacturer	Generic Name	Color Index No.	Amount Used (%)
A	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	6.48
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	3.89
B	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	6.48
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	3.89
C	Celliton Fast Red Violet RNA	GAF	Disperse Violet 1	61100	12.19
	Sandocryl Blue B-RLE	Sandoz	Basic Blue 41	11154	3.20

Visual inspection of the dyed and finished fabrics clearly showed that the dyeing cycle used prevented the formation of wrinkle/cracks in the fabrics.

The physical properties of the undyed and production dyed and finished fabrics are shown in Table 14, and the colorfastness and flammability properties are shown in Table 15.

It was agreed with NCTRF that the required dimensional stability test would be conducted at their laboratories, since AI Research Co. does not have the necessary equipment to conduct such tests. Furthermore, it was agreed that there was no need to conduct antistatic tests before or after laundering or the testing for permanent press properties since the finish formulation did not contain additives which would impart such properties. Also the Nonfibrous Content Test (Test Method 2611) would not be run since the method is not applicable to finished fabrics.

Discussion and Conclusions. The results in Table 14 show that the production dyed fabric properties are generally satisfactory and reasonably consistent with those obtained in the pilot plant trials in Phase II. The action of desizing, dyeing and finishing has allowed the fabrics to shrink slightly, as shown by the yarn count; has probably bulked and flattened the yarns somewhat so that the permeability of Fabric C is reduced; and has doubtless relaxed residual stresses permitting a more uniform stress distribution and, consequently, a higher measured breaking strength.

Fabrics A and C show a somewhat larger loss in strength than was found in Phase II. The fact that Fabrics A and B were processed together, and that B shows no loss in tear strength, suggests that the loss in Fabric A, as well as in Fabric C, is most likely associated with variation in yarns used to manufacture the fabrics rather than the effects of chemicals or wet processing conditions. More detailed sampling of the undyed fabric would be needed to confirm this hypothesis. However, all observed tear strengths remain well above the minimum value commonly given for apparel fabrics.

The application of the finish improved the abrasion resistance of each of the fabrics, for example, Fabric A was improved by a factor of almost 3, whereas Fabrics B and C were improved by a factor greater than 3.

Table 15 shows that the colorfastness properties are generally good to excellent. Colorfastness to laundering is acceptable but staining on the acetate and nylon test fabrics in the wash test shows that the dispersed dye leached out of the dyed fabric. The fact that a more severe scour (increased alkalinity) failed to decrease the leaching of dye from Fabric C during laundering indicates that the cause is related to inadequate attachment of the dispersed dye to the Kynol fiber. Presumably, an improvement may be expected by locating a more suitable dispersed dye.

Lightfastness was again found to be poor because of the inherent nature of the phenolic fiber, which darkens rapidly on exposure to light.

Table 14. Fabric Characteristics (Phase III)

Property	Test Method	Condition	Sample A Warp	Sample A Fill	Sample B Warp	Sample B Fill	Sample C* Warp	Sample C* Fill
Weight (oz/yd^2)	5041		5.6		7.5		11.3	
Breaking strength (lbs)	5100	undyed	95	82	131	94	145	120
		dyed[1]	106	79	174	104	198	132
Tear strength ($1x10^2$ gms)	5132	undyed	29	27	29	17	37	28
		dyed[1]	23	18	33	16	31	18
Thread/inch	5050	undyed	52	46	80	46	78	50
		dyed[1]	55	49	81	44	82	51
Air permeability (cu ft air/min/ft^2 fabric)	5450	undyed	94		17		28	
		dyed[1]	89		20		15	
Abrasicn (cycles)	5302	undyed	30		90		270	
		dyed[1]	89		331		935	

[1]Production

Table 15. Colorfastness and Flammability Properties of Finished Fabrics (Phase III)

Fabric Identification BR Dispersion Finish	Laundering, TM 5610 Color Change Pass or Fail	Laundering, TM 5610 Staining Pass or Fail	Perspiration, Test Method 5680 Alkaline Color Change	Alkaline Staining	Acid Color Change	Acid Staining	SFH Light TM 5660	Crocking TM 5651 Wet	Crocking TM 5651 Dry	pH, TM 2811	Flammability, Test Method 5903 Char Length (inches)** Warp	Char Length (inches)** Fill	After Glow (seconds) Warp	After Glow (seconds) Fill	After Flame (seconds) Warp	After Flame (seconds) Fill
Fabric A	Pass	Fail	Excellent		Excellent		Fail 20	Good	Good	7.7	2.700	2.750	0	0	0	0
		A* Good														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric B	Pass	Fail														
		A* Fair	Excellent		Excellent		Fail 20	Good	Good	6.5	3.050	2.700	0	0	0	0
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														
Fabric C	Pass	Fail	Excellent		Excellent		Fail 20	Good	Good	6.2	2.300	2.100	0	0	0	0
		A* Poor														
		C Excellent														
		N Poor														
		P Excellent														
		A Excellent														
		W Excellent														

Lamp calibration
L-4
Wool standard

SFH = Standard Fading Hours

Key: *=Acetate, C=Cotton, N=Nylon, P=Polyester, A=Acrylic, W=Wool.

**Values for the undyed fabrics

	Char Length (in.) Warp	Char Length (in.) Fill
A	2.450	2.900
B	2.300	2.175
C	2.000	1.825

no after glow or after flame

The flammability of the dyed fabric is very similar to the undyed fabric. The values indicate that this important inherent property has been unaffected by the dyeing and finishing processes.

Repeatability of Dyeing Formulation. Based on both laboratory and plant work, it has been established that the formulation used to dye the Kynol/Nomex blended fabrics can be replicated. The dye formulations do not appear to present any unusual problems concerning additions of dyes to match shades. All procedures used are consistent with good commercial plant practices and, if they are properly applied, there should be no difficulty in dyeing any quantity of fabric in a commercial operation.

Estimated Costs for Dyeing and Finishing. The following estimate of costs for finishing a linear yard of Kynol/Nomex fabric is based on the cost of dyes, chemicals and machine charges for production dyeing of the submitted Fabrics A, B and C at Native Textiles. No attempt has been made to include the additional charges that a plant can be expected to add for its services.

Furthermore, these cost estimates are based on machine loads of 225 lbs (one port jet dyeing machine) and a total volume of 400 gallons (water and chemicals).

It should be further noted that machine costs and methods of preparing the fabric for dyeing can be expected to vary among commission dyeing and finishing plants.

Estimated cost of finishing one linear yard of Fabric A = \$2.43
Estimated cost of finishing one linear yard of Fabric B = \$3.21
Estimated cost of finishing one linear yard of Fabric C = \$4.45.